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NASA

COMMERCE LAB

SCIENCE

COMMERCE LAB:
MISSION ANALYSIS AND
PAYLOAD INTEGRATION STUDY

INTERIM PROGRESS REPORT

DECEMBER 6, 1984

CONTRACT NAS8-36109

WYLE LABORATORIES

INDUSTRY

P-11-84-33

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PREFACE

The U. S. space program has progressed considerably since the days of Apollo and Skylab in the late sixties and early seventies. At that time, experiments and scientific demonstrations were performed on the usefulness of microgravity in fluid physics and on a range of solidification processes. In those days, sample return to Earth was quite limited. The development and successful flight of the Space Shuttle provides the long-awaited capability to launch and return sizable samples to space for scientific and commercial reasons. The interest of the scientific community and, in particular, the surge of interest being shown toward commercial utilization of space for microgravity processes demands that a vigorous flight program be pursued. In fact, this is one of the strong recommendations of NASA's Space Commercialization Task Force. In addition, the commercial user generates a need for a well-defined infrastructure for operation.

The number of missions currently planned for the next 8 to 10 years is insufficient to support an aggressive commercial microgravity program. Therefore, this program, "Commerce Lab: Mission Analysis Payload Integration Study," will identify needs, define missions, and, to some extent, identify and analyze infrastructural issues.

A commercial laboratory facility which can be used to develop studies in microgravity science and technology as well as to resolve institutional and policy issues related to private sector involvement in the space program is a proposed addition to NASA's mission planning. Commerce Lab is conceived to be one or more of an array of carriers which would fly aboard the Space Shuttle that will accommodate microgravity science experiment payloads. Of equal importance to the task of defining commercial missions is the determination of the status of the experiment development and particularly the state of affairs of the experiment apparatus inventory and its capabilities to support the industrial scientists' requirements.

It is expected that Commerce Lab will provide a logical transition, or bridge, between currently planned Space Shuttle missions and future microgravity missions centered around the Space Station. The current Space Shuttle traffic model envisions a number of flights per year with Microgravity Science and Applications (MSA) experiments scheduled for the middeck, on the Materials Experiment Assembly (MEA) located in the payload bay and in Spacelab. However, additional emphasis needs to be placed on the current Space Shuttle mission model for MSA studies. The mission model for Commerce Lab should address both scientific interest and commercial applications. Whereas many of these mission requirements may only be resolved by having an operational Space Station, it is important to gain further insight into MSA during the develomental years of Space Station to ensure that the Space Station is not plagued with similar limitations.

WYLE TEAM MEMBERS

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TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

BIO - Biotechnology
CDMS - Command and Data Management System
CIEF - Continuous Isoelectric Focusing
CS - Combustion Sciences
EM - Electronic Materials
F&T - Fluids and Transports
FDOR - Final Design and Operations Review
FRR - Flight Readiness Review
G&C - Glasses and Ceramics
GAS-Can - Get-Away-Special cannister
GSE - Ground Support Equipment
ICD - Interface Control Document
IDE - Initial Design Evaluation
IEF - Isoelectric Focusing
INTEG - Integration
IRR - Integration Readiness Review
M&A - Metals and Alloys
MEA - Materials Experiment Assembly
MPESS - Mission-Peculiar Experiment Support Structure
MPS - Material Processing Science
MSA - Microgravity Science and Applications
MSL - Material Science Laboratory
POCC - Payload Operations and Control Center
REQ - Requirements
RIEF - Recirculating Isoelectric Focusing
RR - Requirements Review
STS - Shuttle Transportation System

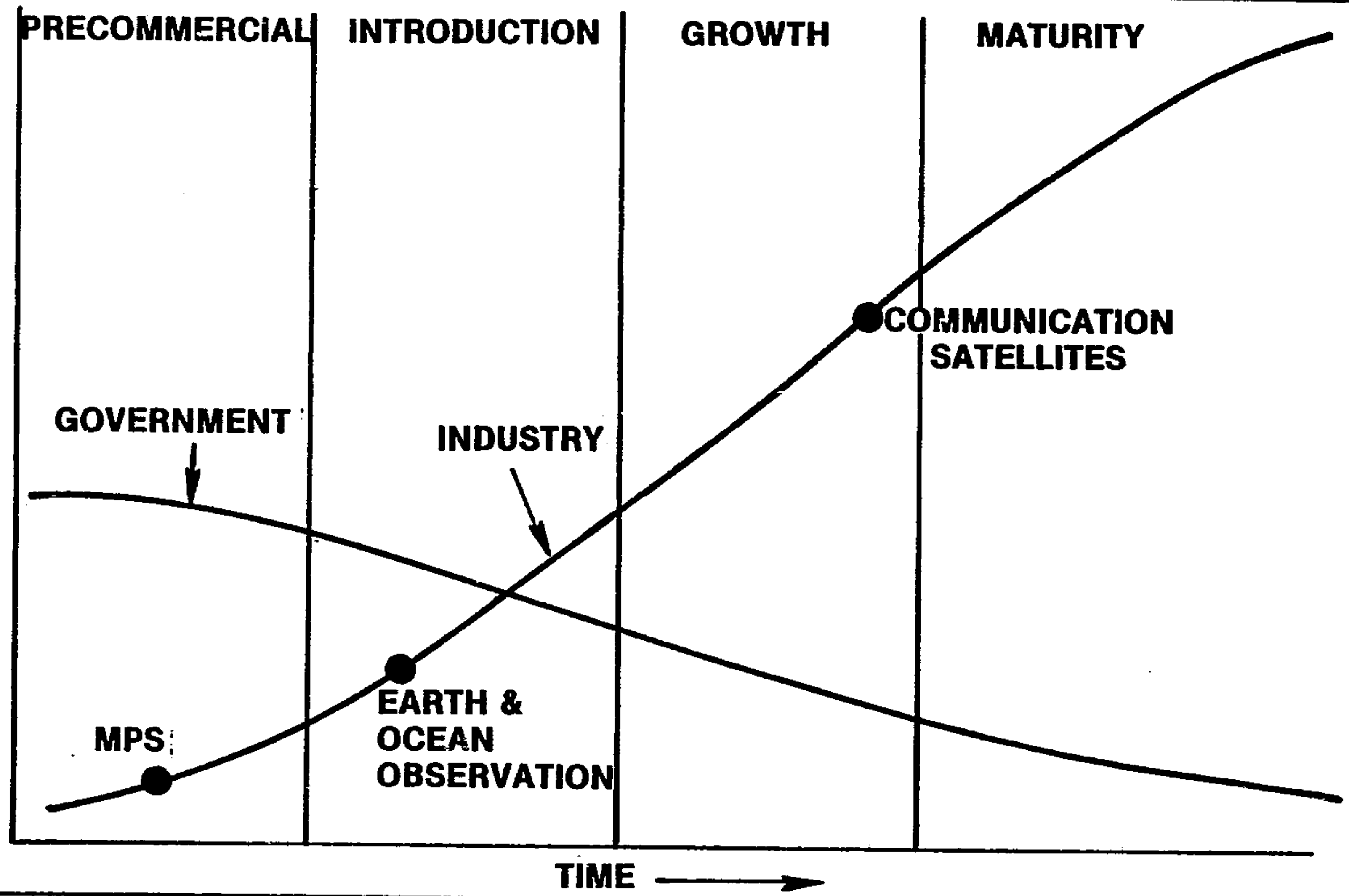
INTRODUCTION

RELATIVE ROLES OF INDUSTRY AND GOVERNMENT IN COMMERCIALIZATION

Within the timeframe of a program's development, the roles taken by industry and government in the commercialization of a process are inverse relative to each other. That is, industry should place an increasing emphasis on and invest an increasing amount of time and money in a specific program while government's involvement in that program decreases.

The chart shows three example space programs and their relative maturity with respect to each other as well as the relative roles of government and industry in program commercialization. It should be noted that industry's role does not reach a plateau but continues to increase, reflecting commercial spin-offs from the original program. Government will, in all likelihood, remain a participant as a regulatory agency and/or customer. Also, the government should branch out into other processes anticipated to have commercial potention. This could mean that the total government investment would increase while diminishing on an individual process being pursued by private industry.

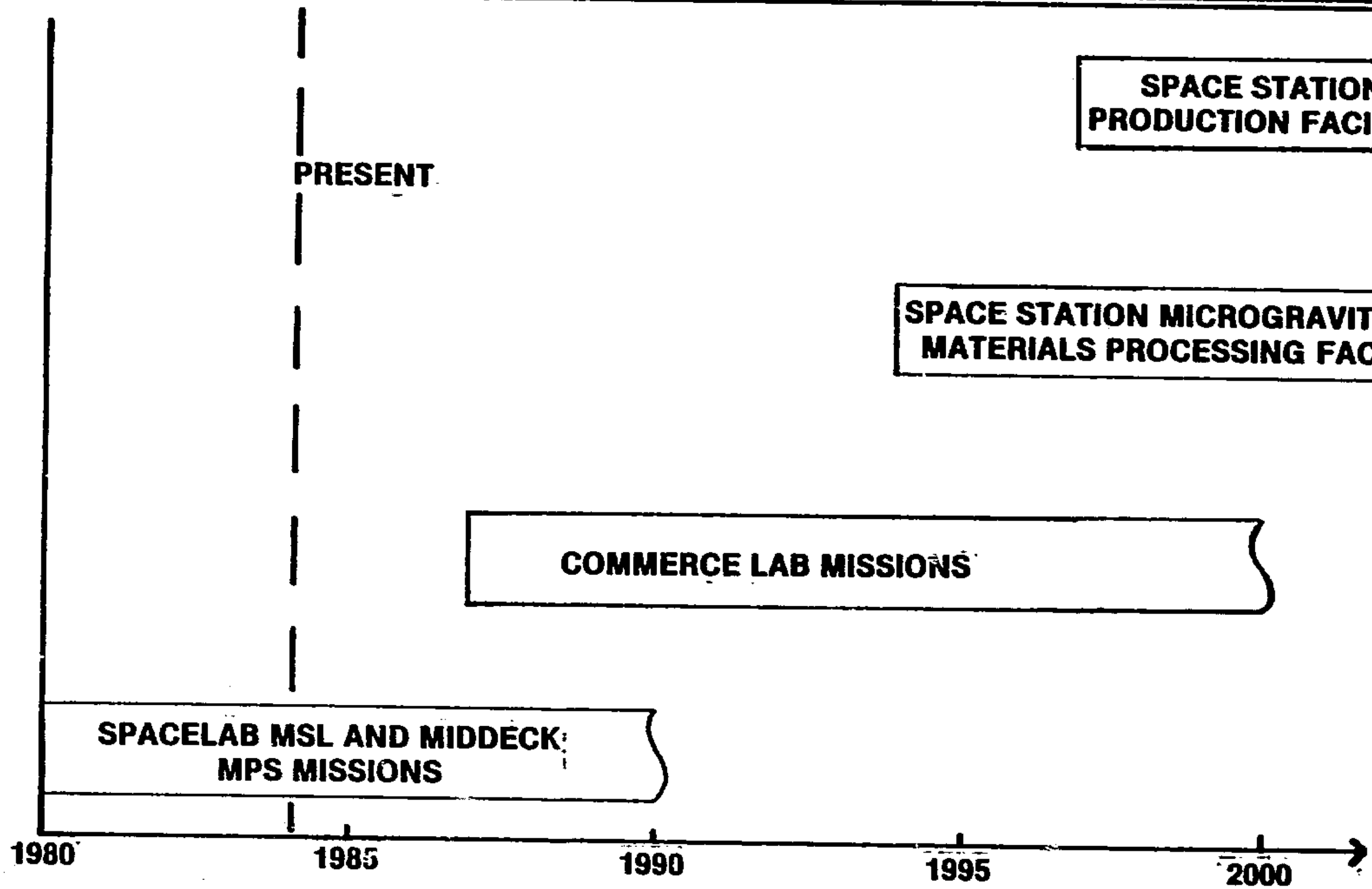
RELATIVE ROLES OF INDUSTRY AND GOVERNMENT IN COMMERCIALIZATION



A NEW COMMERCIAL INITIATIVE

Commerce Lab can serve as a new initiative to industry to actively participate in the commercialization of space. Using existing Spacelab and STS carriers, procedures, and technology, Commerce Lab will allow industry to study and perfect microgravity science and materials processing today without having to wait for the realization of Space Station. Commerce Lab will also serve as a vehicle for the testing and perfecting of hardware and procedures to be used in Space Station so that a full-fledged production facility can be initiated within a year or two of Space Station's insertion into orbit.

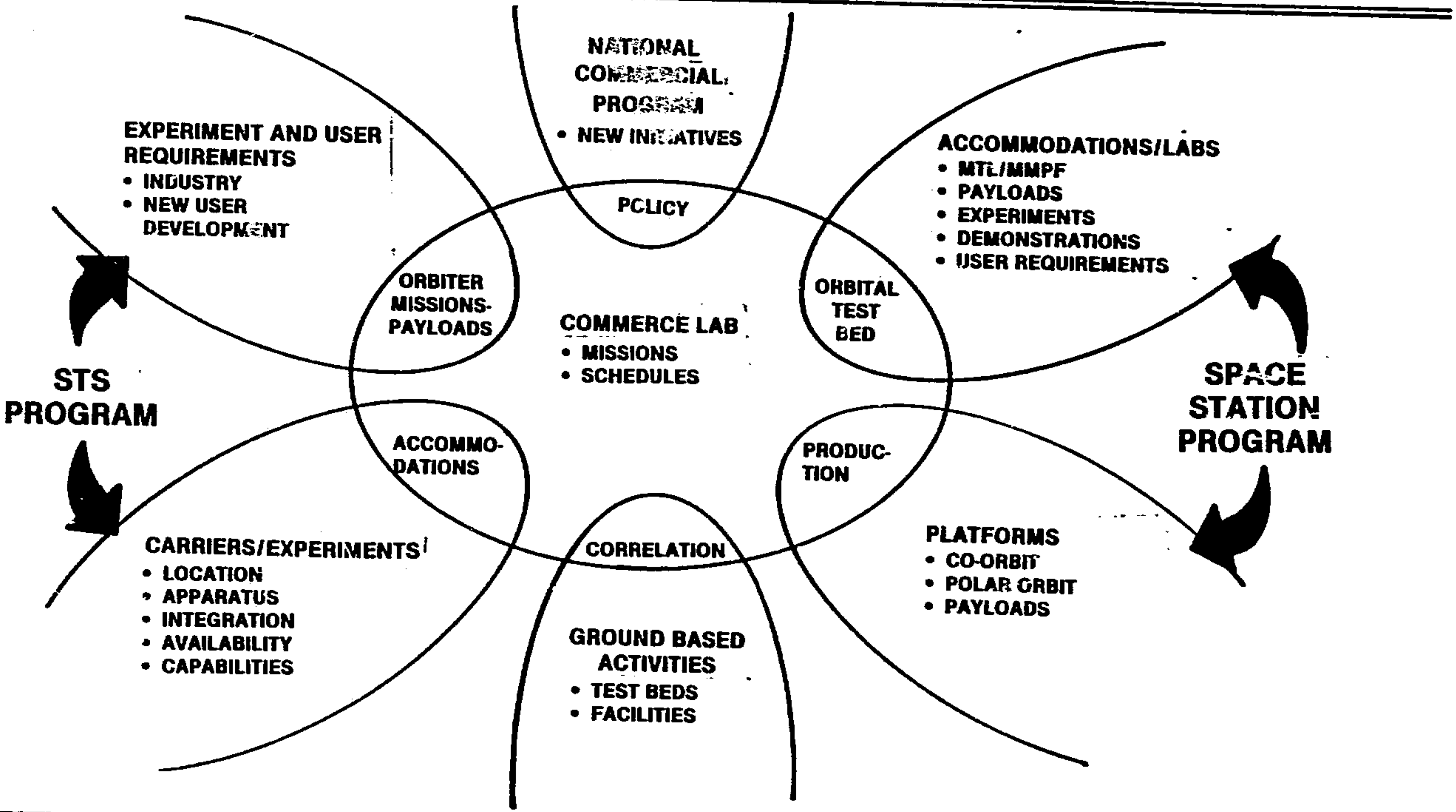
A NEW COMMERCIAL INITIATIVE



RELATIONSHIP BETWEEN COMMERCE LAB PROGRAM AND OTHER SPACE PROGRAMS

Expanding upon the relationships of Commerce Lab, STS, Space Station, government, and ground-based activities, it can be seen that the interactions are numerous and self sustaining. Commerce Lab will be the facility used to implement national commercialization programs and initiatives while serving to develop and scope a realistic government policy in space. Commerce Lab will augment and correlate current and planned ground-based activities such as test beds, drop towers, and ground-based aircraft testing. Commerce Lab will serve as an adjunct to the STS program by providing a focal point for space commercialization and an easier, faster, and more standardized interface for industry wanting to take advantage of manned microgravity capabilities. STS will provide mission availability, carrier and apparatus capabilities, and integration facilities while Commerce Lab will provide viable commercial payloads and user demand. Finally, Commerce Lab will serve as an orbital test facility for the testing, development, and implementation of hardware and procedures to be used in the Space Station program, providing the ability to enhance Space Station development and, as a result, hasten space platform production capability.

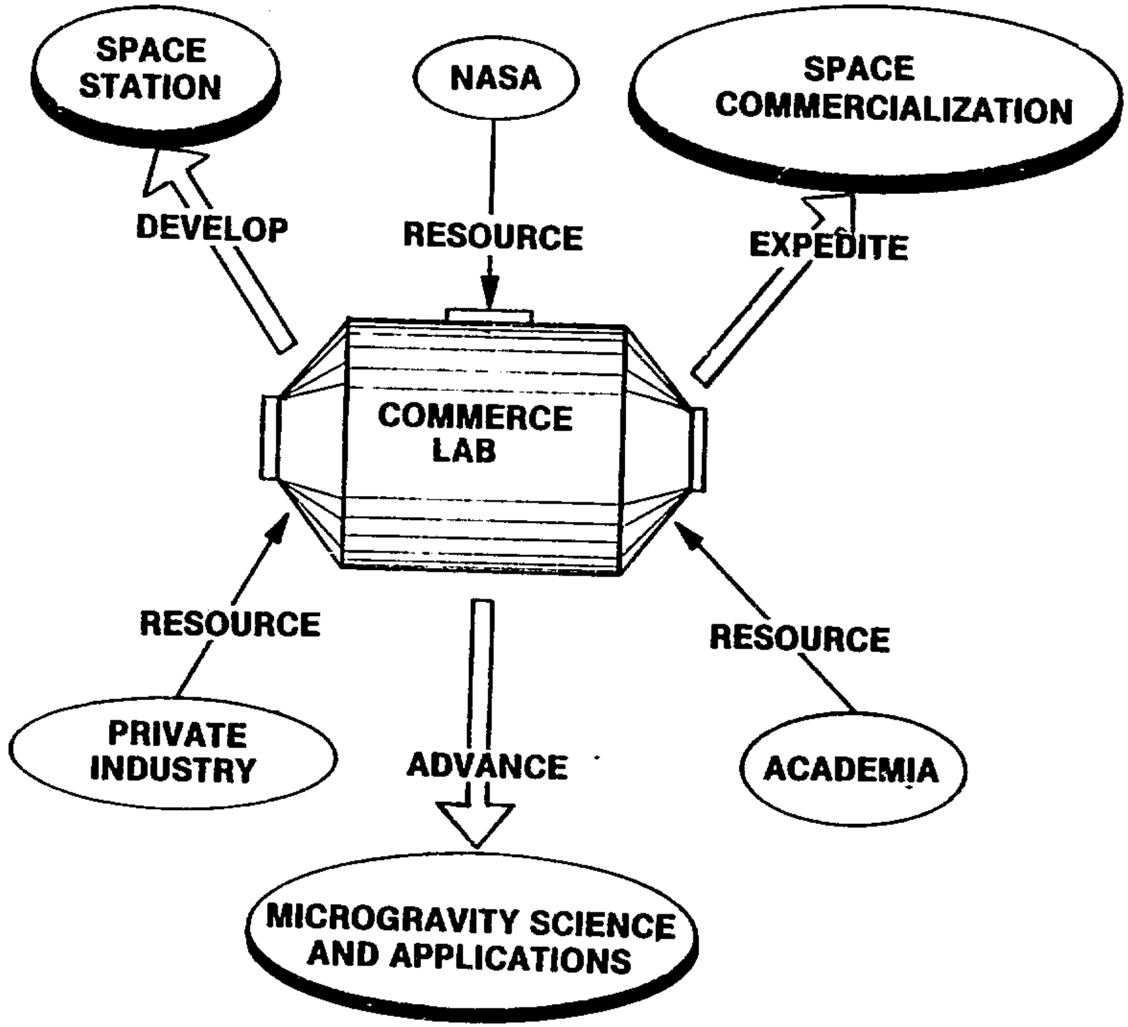
RELATIONSHIP BETWEEN COMMERCE LAB PROGRAM AND OTHER SPACE PROGRAMS



COMMERCE LAB OBJECTIVES

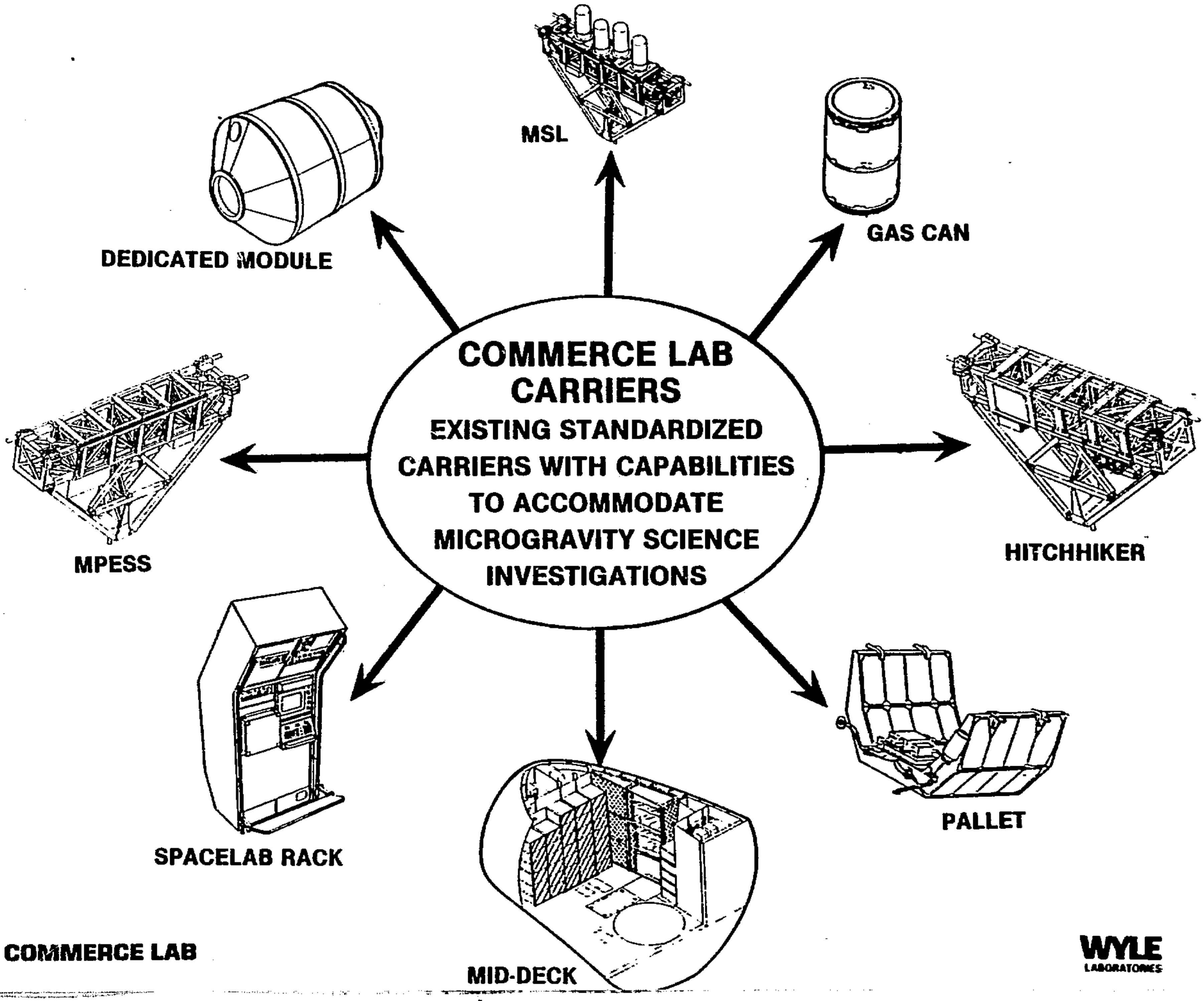
Basically, the objectives of Commerce Lab are threefold: to expedite the commercialization of space as advocated by White House initiatives, to advance the studies of microgravity science and thereby enhance commercial applications of those studies, and to serve as a precursor stage to develop hardware and procedures for use in Space Station. To enable Commerce Lab to reach these objectives, private industry, academia, and NASA will provide resources to the program in the form of interest, time, money, and hardware.

COMMERCE LAB OBJECTIVES



COMMERCE LAB CARRIERS

Utilization of existing carriers will enable Commerce Lab to accommodate microgravity science investigations immediately without the time delays and additional expense of developing new carriers. Standardization of interfaces will hold down development costs and maintain integration time at a minimum. It should be noted, however, that the list of carriers is not limited to those illustrated, and the option of modifying existing carriers and/or development of new carriers is held open for possible future needs.


COMMERCE LAB
CARRIERS
EXISTING STANDARDIZED
CARRIERS WITH CAPABILITIES
TO ACCOMMODATE
MICROGRAVITY SCIENCE
INVESTIGATIONS
MSL
GAS CAN
DEDICATED MODULE
HITCHHIKER
MPESS
PALLET
SPACELAB RACK
MID-DECK

PROGRAM PHILOSOPHY

We can say, then, that Commerce Lab will serve as a focal point for the commercialization of space, especially in the microgravity materials processing sciences, and provide a means for NASA and private industry to cosponsor Shuttle flights partially or wholly dedicated to MPS. In addition, Commerce Lab will serve as the developmental stage of Space Station.

Keeping this basic philosophy in mind, Wyle's study will develop a mission model which will accommodate commercial users and provide a basic data base for future mission planning.

PROGRAM IMPLEMENTATION

- PROGRAM PHILOSOPHY:
  - TO PROVIDE A POINT OF FOCUS FOR IMPLEMENTING A SERIES OF SHUTTLE FLIGHTS, CO-SPONSORED BY NASA AND U.S. DOMESTIC CONCERNS, FOR THE PURPOSE OF PERFORMING MATERIALS PROCESSING RESEARCH AND PRE-COMMERCIALIZATION INVESTIGATIONS

- WYLE STUDY OBJECTIVE:
  - TO DEVELOP A MISSION MODEL FOR ACCOMMODATING COMMERCIAL MPS USERS

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PROGRAMMATICS

BACKGROUND

- CONTRACT WAS INITIATED ON JUNE 22, 1984
- KICKOFF MEETING AT MSFC ON JULY 6, 1984
- REVIEWS WITH MSFC ON AUGUST 22 & OCTOBER 17, 1984
- PERIOD OF PERFORMANCE: 12 MONTHS

MAJOR PROGRAM TASKS

The four tasks defined in the contract are given on the facing page. There have been some changes with regard to the emphasis being placed on some areas. Three things are worthy of noting. First, NASA has requested that Wyle take a quick look into integration times and concepts for reducing user integration time. Second, analysis of infrastructural relationships has been de-emphasized as requested by NASA; and third, it has been necessary to refine and expand the approach logic, taking into account all possible contingencies. (Detailed flowcharts are available.) The status of the tasks are briefly summarized on the following page (see schedule).

CONTRACT STUDY TASKS

TASK I - SYNTHESIS OF USER REQUIREMENTS AND IDENTIFICATION OF COMMON ELEMENTS AND VOIDS

TASK II - DEFINITION OF PERFORMANCE AND INFRA-STRUCTURE REQUIREMENT AND ALTERNATIVE APPROACHES

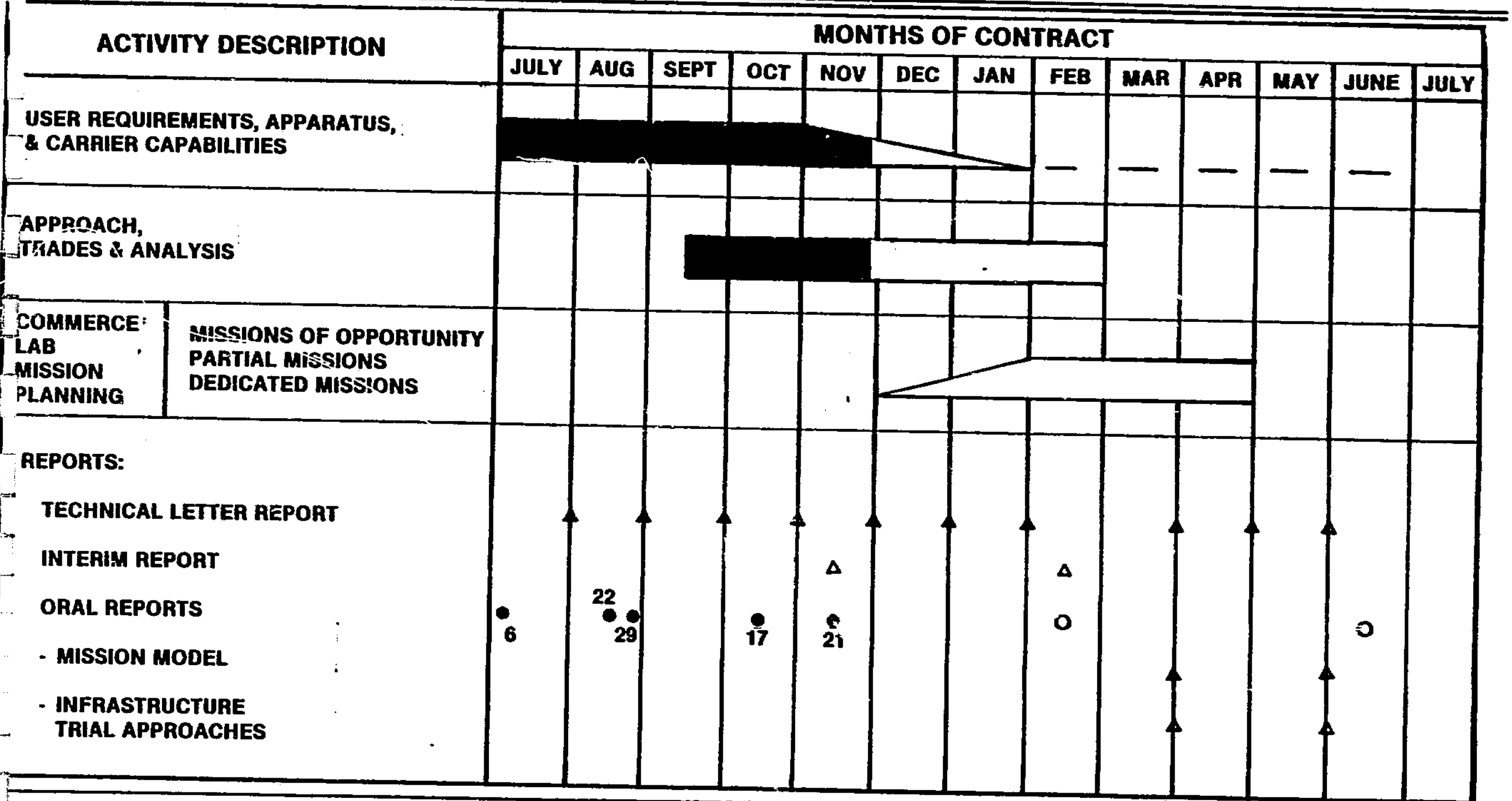
TASK III - CARRIER AND MISSION MODEL DEVELOPMENT AND INFRASTRUCTURE DEVELOPMENT

TASK IV - PREPARATION OF FINAL REPORT

SCHEDULE

The schedule on the facing page has been developed commensurate with the tasks current in work (see preceding page). Task I is, for all intents and purposes, complete. Corrections, additions, and deletions may be made over the remainder of the study as required by the increasing maturity of the user investigations. Task II is in work. The approach logic for mission planning and mission model development has been refined and expanded in flowchart form. The mission analysis and planning part of Task II has been initiated. Task III will be initiated as per the schedule.

PROGRAM SCHEDULE



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APPROACH

CONSIDERATIONS

The Commerce Lab program must take into account a myriad of complex considerations which constitutes the fabric of space commercialization. The technical approach for the Commerce Lab Study recognizes these various considerations and provides an analytical framework for structuring the elements and deriving the mission set.

The six microgravity science disciplines must be expanded into their many investigation areas and then screened for potential commercial applications. User interest and requirements are key drivers in the development of a comprehensive set of experiment apparatus requirements.

Experiment apparatus is a fundamental consideration. The apparatus inventory shall include those presently available to industry, those currently under development, and identifiable apparatus needed in the future.

Existing carriers identified for commercial applications represent the foundation for the experiment payload accommodations. Near-term and long-term requirements may dictate modifications or refinements to the existing carrier inventory or new carriers will be recommended.

Integration of the user payloads and methods of providing a more timely access to space and reduced time waiting to be incorporated into missions are paramount to developing the user community.

Trades and analysis are essential in deriving the best mission(s) for both the commercial user and NASA. User requirements, apparatus capabilities, and carrier capabilities are played against missions of opportunities and the STS mission model in the trades and analysis and mission planning elements in an iterative process to define a Commerce Lab mission set. Infrastructure and nontechnical issues as they affect Commerce Lab will be identified and recommended solutions will be presented.

CONSIDERATIONS

1. MICROGRAVITY SCIENCE DISCIPLINES HAVING POTENTIAL COMMERCIAL APPLICATION

2. USER INTERESTS AND REQUIREMENTS

3. EXPERIMENT APPARATUS
   a. PRESENTLY AVAILABLE
   b. UNDER DEVELOPMENT
   c. FUTURE NEEDS

4. ACCOMMODATIONS
   a. EXISTING CARRIERS
   b. NEAR-TERM REFINEMENTS (MODIFICATIONS TO EXISTING CARRIERS)
   c. LONG-TERM REQUIREMENTS

CONSIDERATIONS
(Continued)

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5. INTEGRATION
   a. EXISTING PROCESS
   b. ALTERNATIVES LEADING TO NEW INTEGRATION CONCEPTS
   c. INTEGRATION/USER INTERFACE TRADES

6. TRADES AND ANALYSES NECESSARY TO SUPPORT MISSION PROJECTIONS

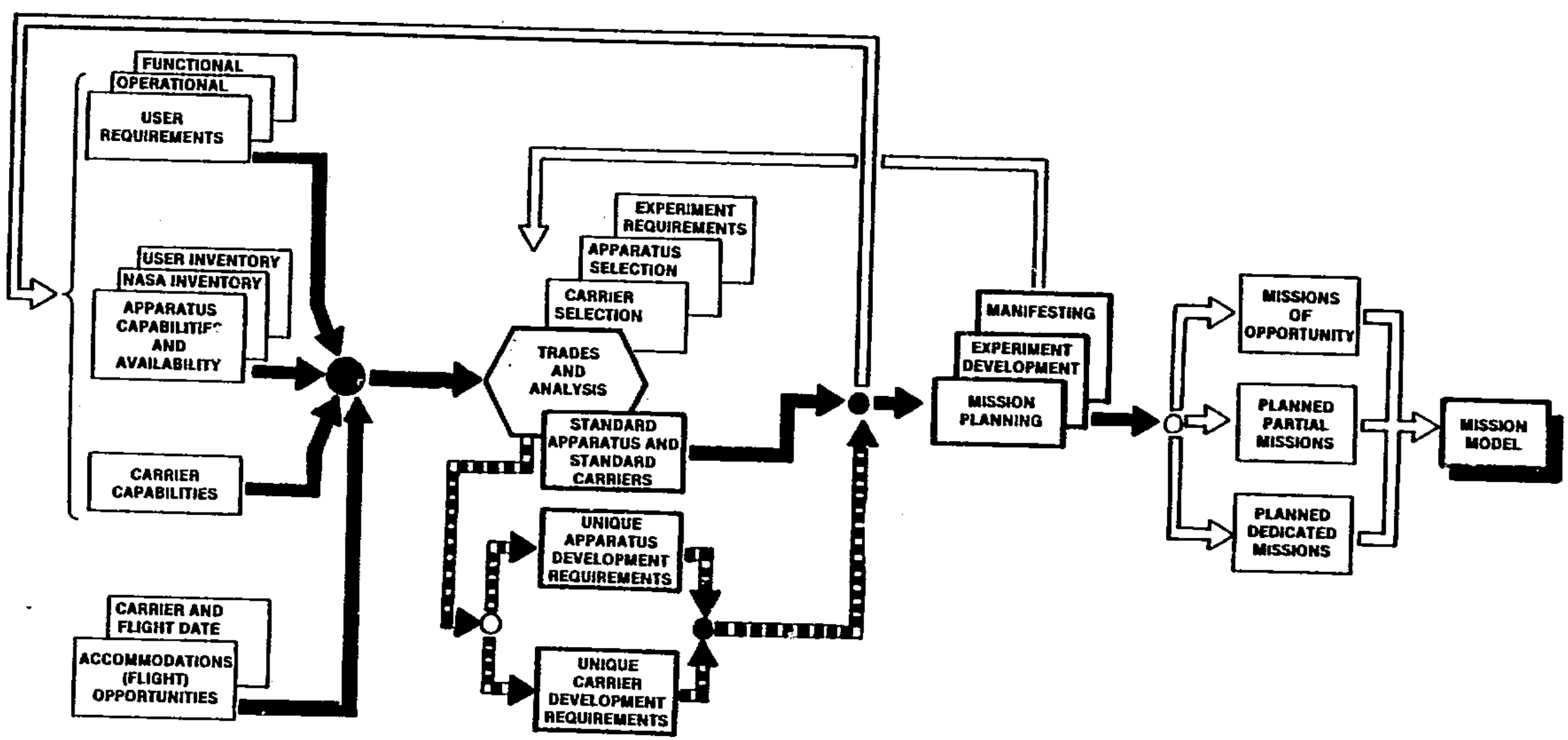
7. MISSION MODEL DEVELOPMENT

8. INFRASTRUCTURE AND NONTECHNICAL ISSUES

COMMERCE LAB STUDY FLOW

The study flow presents a simplified block diagram of the elements of the Commerce Lab study with some of the more pronounced interrelationships. The diagram indicates that three elements of the study: (1) user requirements, (2) apparatus capabilities and availability, and (3) carrier capabilities along with missions of opportunity are entered into the trades and analysis element. In the trades and analysis, three discriminator paths are examined: (1) standard apparatus and standard carriers, (2) unique apparatus development requirements, and (3) unique carrier development requirements. Satisfaction of user requirements is initially sought with the standard apparatus and standard carriers, and a mission is identified. Mission trades must be conducted in an interactive mode with the user. A dialog with the user can result in examining alternative missions which will provide varying degrees of user satisfaction. The user may desire to examine other alternative missions based on modification of user requirements or consider a modification of existing apparatus or a new apparatus or possibly a modification of an existing carrier or a new carrier. Each alternative will carry benefits and penalties for the user who must weigh these factors in terms of his own goals, objectives, and cost constraints. These decisions cannot be arrived at until the mission planning element has been completed for the various alternatives. It is within the mission planning element that the various development times and the processing and integration times for an alternative are arrived at and a match-up with the STS mission model is identified. There are two feedback loops indicated in the study flow. The first ensues from the trades and analysis back to the three input elements, any of which can be changed at the discretion of the commercial user. The second feedback loop is from the mission planning element to the trades and analysis. The essential feature concerning the approach employed in the study flow is that within the trades and analysis element and the mission planning element an interactivity and a continuing dialog with the commercial user are the key to the program's success.

STUDY FLOW



FUNCTIONAL
OPERATIONAL
USER REQUIREMENTS
USER INVENTORY
NASA INVENTORY
APPARATUS CAPABILITIES AND AVAILABILITY
CARRIER CAPABILITIES
CARRIER AND FLIGHT DATE
ACCOMMODATIONS (FLIGHT) OPPORTUNITIES
EXPERIMENT REQUIREMENTS
APPARATUS SELECTION
CARRIER SELECTION
TRADES AND ANALYSIS
STANDARD APPARATUS AND STANDARD CARRIERS
UNIQUE APPARATUS DEVELOPMENT REQUIREMENTS
UNIQUE CARRIER DEVELOPMENT REQUIREMENTS
MANIFESTING
EXPERIMENT DEVELOPMENT
MISSION PLANNING
MISSIONS OF OPPORTUNITY
PLANNED PARTIAL MISSIONS
PLANNED DEDICATED MISSIONS
MISSION MODEL

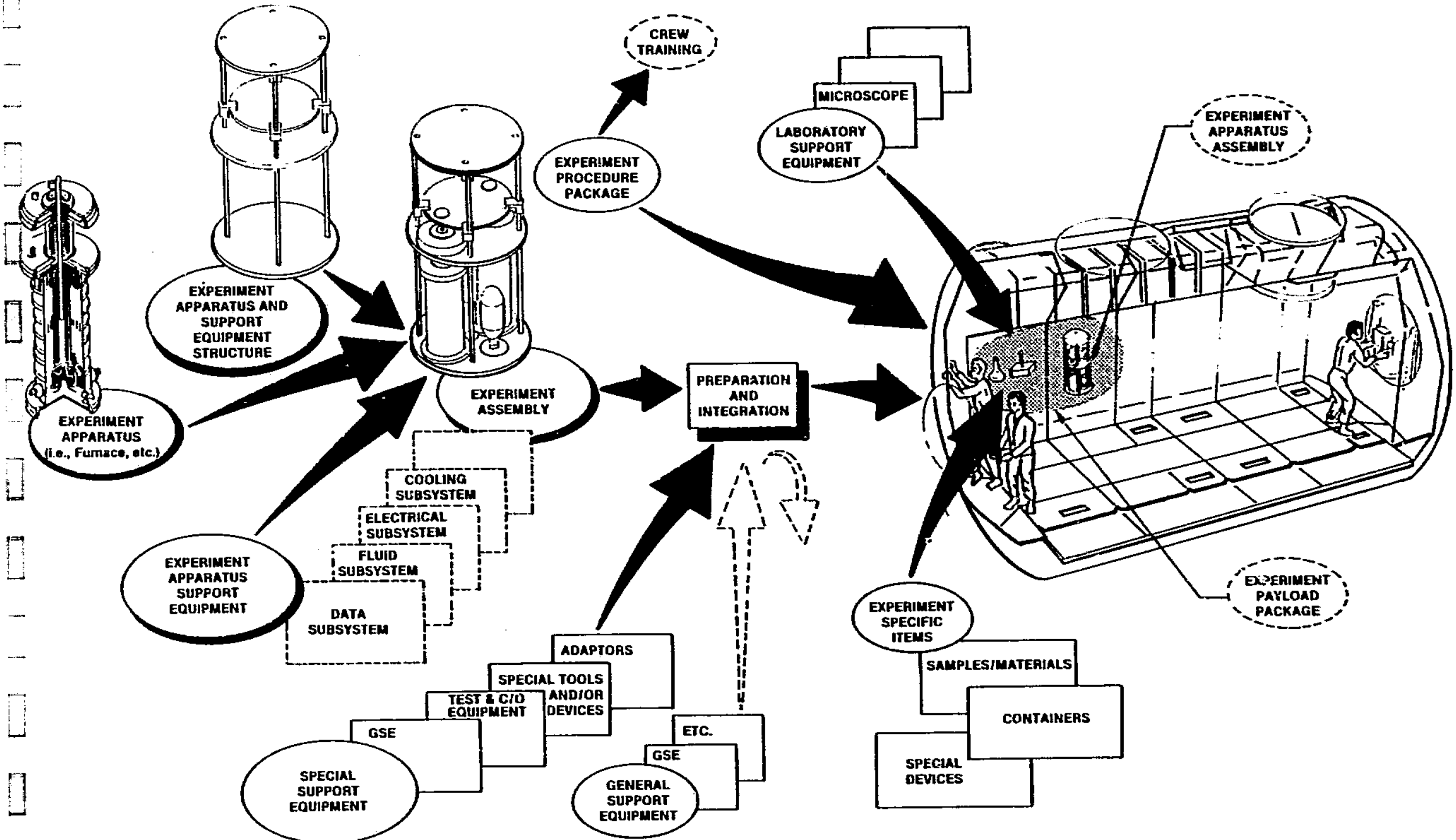
EXPERIMENT PACKAGE ELEMENTS AND REQUISITE SUPPORT EQUIPMENT

An experiment payload package for Commerce Lab is defined as an assemblage of items that is required to enable the experiment to be conducted on-orbit. A distinction is made between what constitutes an experiment apparatus, an experiment assembly, and an experiment payload package. The clarification is exhibited in the diagram. A generic discussion of the various payload-related items is provided. Many of the items are germane only to certain types of payloads and experiments but are presented to give an overall Commerce Lab perspective. The items are as follows:

- An experiment apparatus (such as a furnace) is the central piece of technical equipment or instrument around which the experiment is conducted.
- The experiment apparatus and support equipment structure is a housing or container in which the experiment apparatus and experiment apparatus support equipment are mounted.
- The experiment assembly is the fully assembled experiment apparatus and experiment apparatus support equipment, such as the electrical, cooling, fluid, and data subsystems, housed in the structure.
- Special support equipment includes those items of special ground support equipment, test and checkout equipment, special-purpose tools, devices, and equipment used in the preparation, integration and processing activities.
- General support equipment includes any designated, nonspecific items employed in the preparation, integration, and processing activities.
- Experiment procedure package contains the detailed steps the crew member(s) must carry out on-orbit. It also provides the basis for crew training.
- Laboratory support equipment consists of general laboratory equipment (such as a microscope) required to conduct or support the on-orbit experiment.
- Experiment specific items are those items unique to the experiment and include specific materials and samples, special containers, or other specifically-designated equipment.

Note that the shaded area in the diagram is designated the experiment payload package. It consists of all items necessary to conduct the experiment: (a) experiment apparatus assembly, (b) experiment procedure package, (c) laboratory support equipment, and (d) the experiment-specific items.

EXPERIMENT PACKAGE ELEMENTS AND REQUISITE SUPPORT EQUIPMENT



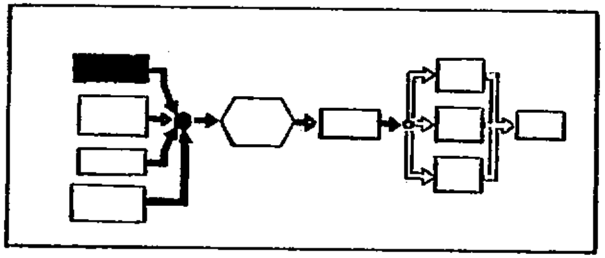
DEVELOPMENT OF USER REQUIREMENTS

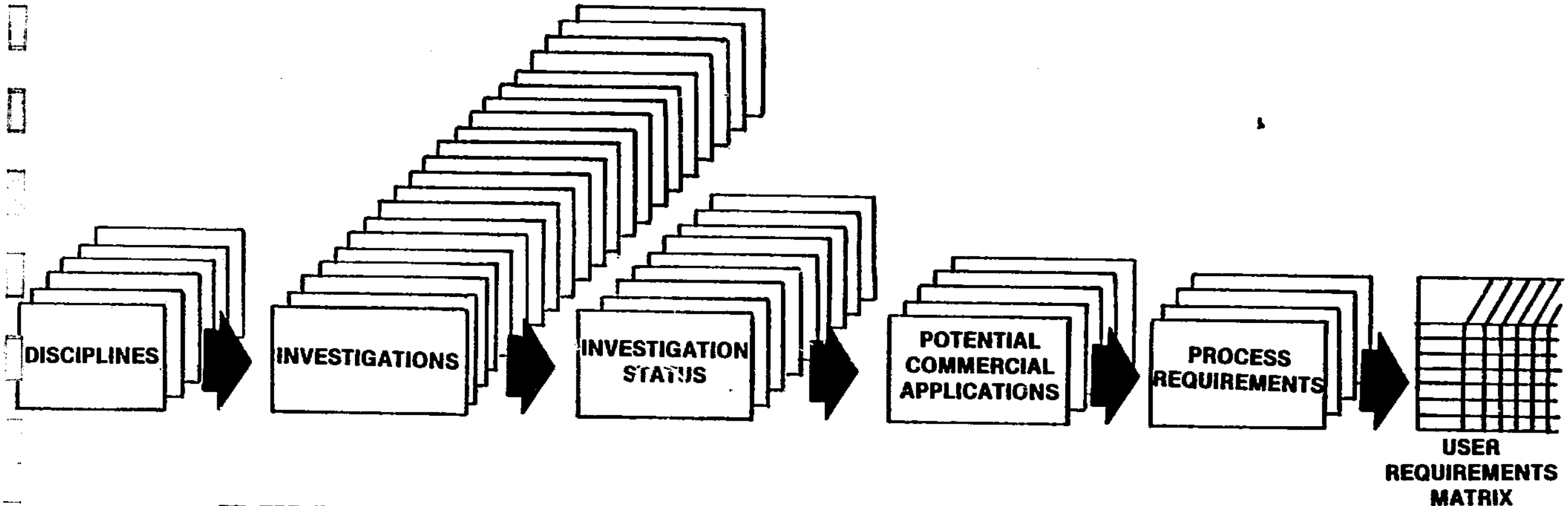
The approach to the development of user requirements was initiated with the six scientific disciplines that NASA uses to categorize microgravity science. These are (1) electronic materials, (2) metals and alloys, (3) ceramics and glasses, (4) biotechnology, (5) fluid and transport phenomena, and (6) combustion sciences. Each of these categories is expanded into investigation categories of scientific knowledge, process development, or product development. Each investigation is further categorized as to whether it is an analytical exercise, a ground-based exercise, or a flight candidate.

The next screening operation results in a narrowing of scope by focusing on those investigations with potential commercial applications. At this step, interested parties with their institutions or industrial firms are identified.

The next step is the identification of process and flight experiment requirements. At this screening, the investigations with potential commercial applications are again narrowed since some investigators will not have identified the operational and/or functional flight requirements.

The end result or output of this activity is a user requirements matrix.





DEVELOPMENT OF USER REQUIREMENTS FOR COMMERCE LAB MISSION ANALYSIS

APPARATUS CAPABILITIES AND AVAILABILITIES

The diagram on the facing page depicts the major elements and activities involved in the process of identifying the capabilities of the apparatus used in the investigations that have an indicated, potential commercial application.

The initial step involves an identification of the apparatus type (i.e. furnace, levitator) and the quantity of each type (quantity helps determine availability).

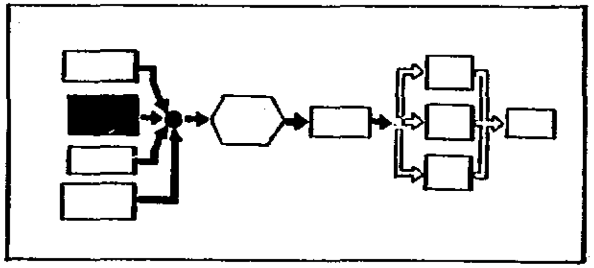
The next step is a determination of the status. This consists of a determination of whether it is a ground or flight piece of equipment. For each category (ground or flight), it is indicated that it is within one of the four categories as follows:

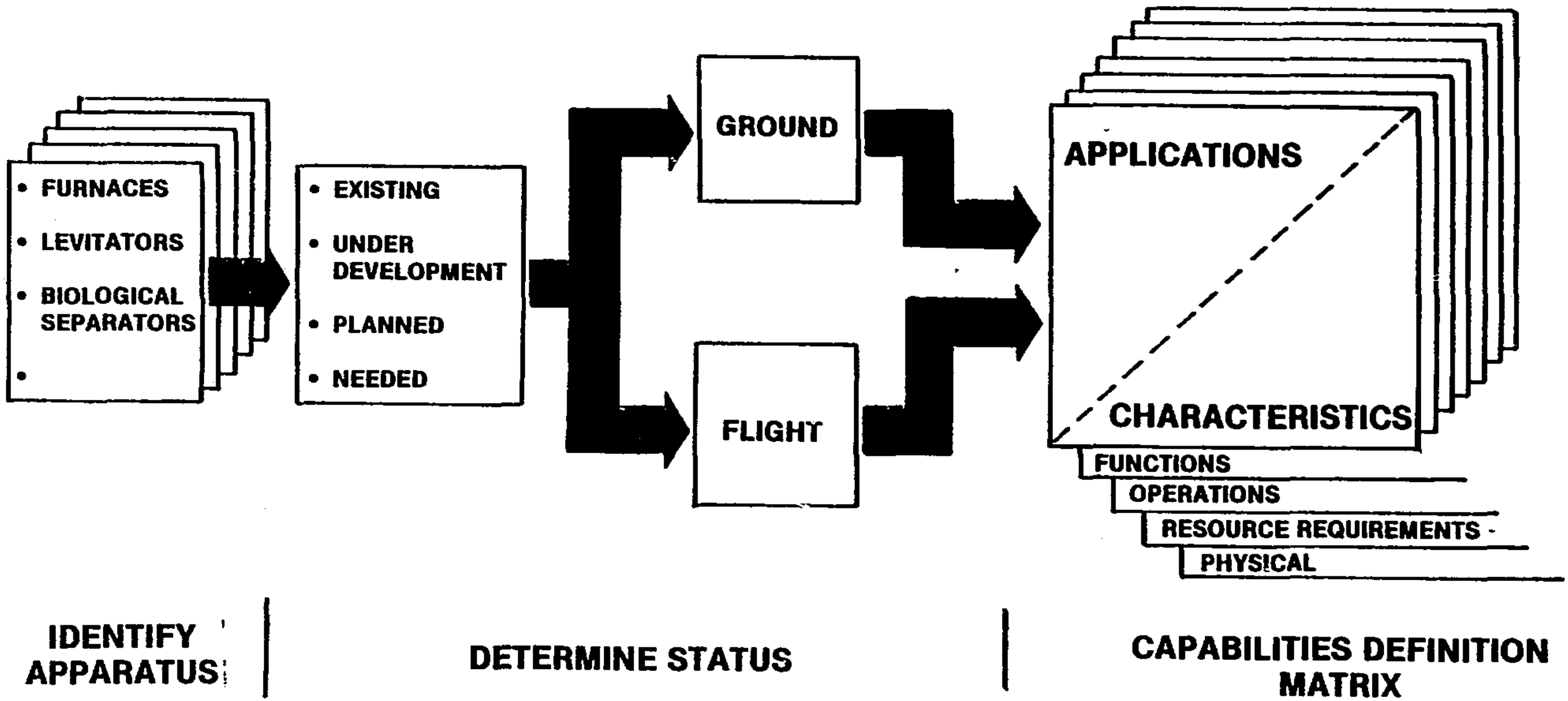
- Existing
- Under development
- Planned
- Needed

The final step provides applications and characteristics which include

- Functional characteristics
- Operational characteristics
- Resource requirements (i.e. utilities, communications, mechanical, computer and data acquisition)
- Physical characteristics and considerations (i.e. dimensions, mass, access, etc.)

The output of this process is the capabilities definition matrix.





DEVELOPMENT OF APPARATUS CAPABILITIES AND AVAILABILITY

CARRIER CAPABILITIES

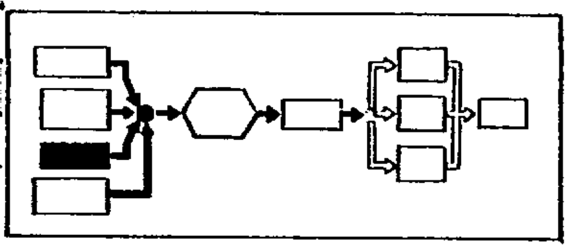
The development of carrier capabilities involves three fundamental steps culminating in the capabilities matrix as shown in the diagram.

The first step is identification of the carrier set or those existing STS carriers that have the capabilities for accommodating an experiment payload. These consist of Spacelab Modules (long and short), Spacelab Pallets, Orbiter Middeck Lockers, Hitchhiker, MSL, MPESS, GAS Can, etc.

The second step is the development of the carrier set data base. This involves interviews with NASA engineers and other cognizant NASA personnel to identify relevant documentation--such as handbooks, instrument interface agreements, interface control documents, and other sources of information--and to ferret out information and data gained through their personal involvements with carriers.

The third step is the identification of resources and discriminators for the carrier equipment. These include power capabilities, heat rejection capabilities, and discriminators such as physical characteristics for accommodating experiment payloads of given dimensions, volume, mass, etc.

The output of this process consists of the capabilities matrix.



IDENTIFY CARRIER SET → DEVELOP CARRIER SET DATA BASE → IDENTIFY RESOURCES AND DISCRIMINATORS FOR CARRIER EQUIPMENT → CAPABILITIES MATRIX

IDENTIFY CARRIER SET

- SPACELAB MODULES
- SPACELAB PALLETS
- MIDDECK LOCKERS
- HITCHHIKER
- MSL
- GAS CAN

DEVELOP CARRIER SET DATA BASE

- HANDBOOKS
- ICD'S
- INSTRUMENT INTERFACE AGREEMENT
- INTERVIEW NASA ENGINEERS
- OTHERS

IDENTIFY RESOURCES AND DISCRIMINATORS FOR CARRIER EQUIPMENT

- POWER
- HEAT REJECTION
- DIMENSIONS
- VOLUME
- MASS
- ETC.

CAPABILITIES MATRIX

DEVELOPMENT OF CARRIER CAPABILITIES MATRIX

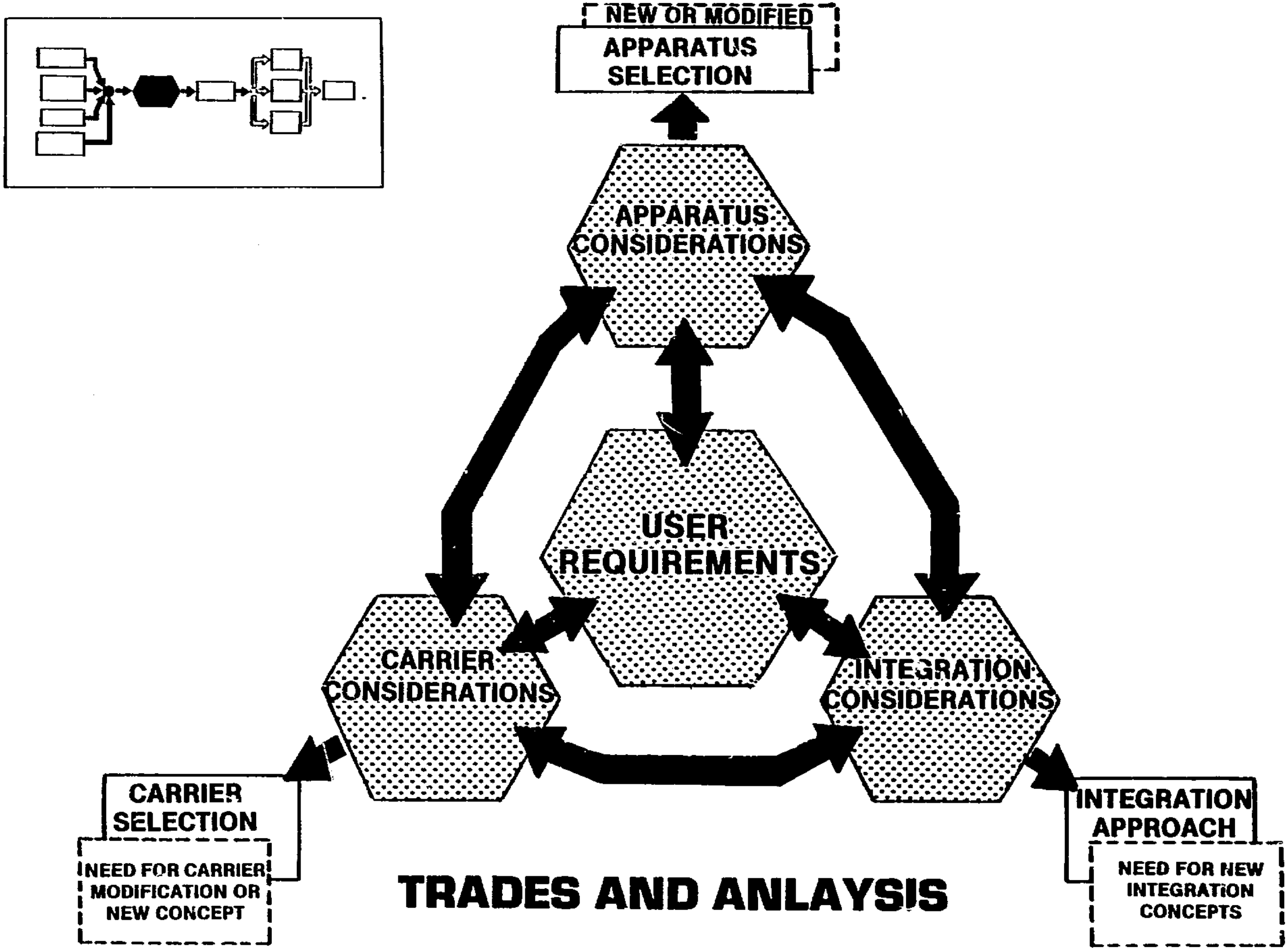
TRADES AND ANALYSIS

Trades and analysis is a user-interactive and iterative process that provides user satisfaction through a selection of apparatus and carrier and an identified mission. User requirements are the forcing function that must be satisfied by trading apparatus capabilities and availability, carrier capabilities, and integration activities against the requirements of the user. During the mechanics of the trades and analysis, a dialog with the user must be maintained. In the diagram, user requirements are the focal point or nucleus around which the apparatus considerations, carrier considerations, and integration considerations revolve. The process is not complete until the user arrives at a flight that satisfies his needs.

Satisfaction of user requirements is initially sought with the standard apparatus and standard carriers. Using the integration and processing time provided in the carrier capabilities matrix, a carrier can be selected that both accommodates the experiment payload and enables a mission to be identified. If this mission timeframe is agreeable to the user, the process proceeds to the mission planning stage. If the user is not satisfied, then the dialog with the user proceeds to alternative courses of action, such as modification of user requirements that changes the scope of the experiment, or it can result in the user seeking a higher degree of satisfaction by modifying the apparatus or a carrier or designing a new apparatus or carrier (feedback to input elements in the study flow). Any change from the initial or baseline requirements will germinate an alternative for which a flight on another mission must be located in the STS mission model.

Each alternative will carry its unique benefits and penalties for the user. The user must weigh these factors within the framework of his own goals, objectives, and cost constraints. Only the user can assess the impact of the alternatives in terms of his own needs and requirements.

Trades and analysis provides a tentative look at the user's place in the STS mission model. A more detailed refinement takes place in the mission planning element where the user gets a final look prior to making his decision.



TRADES AND ANLAYSIS

MISSION PLANNING

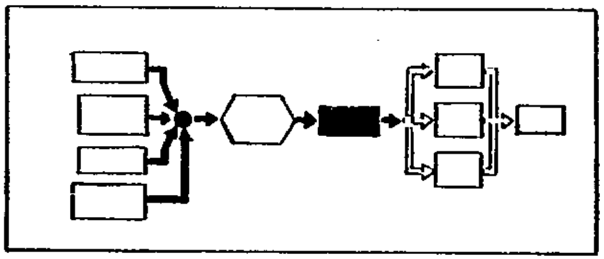
In the trades and analysis phase of the Commerce Lab study, several activities must be accomplished to the satisfaction of the user to enable the process to continue to the mission planning phase. These activities area:

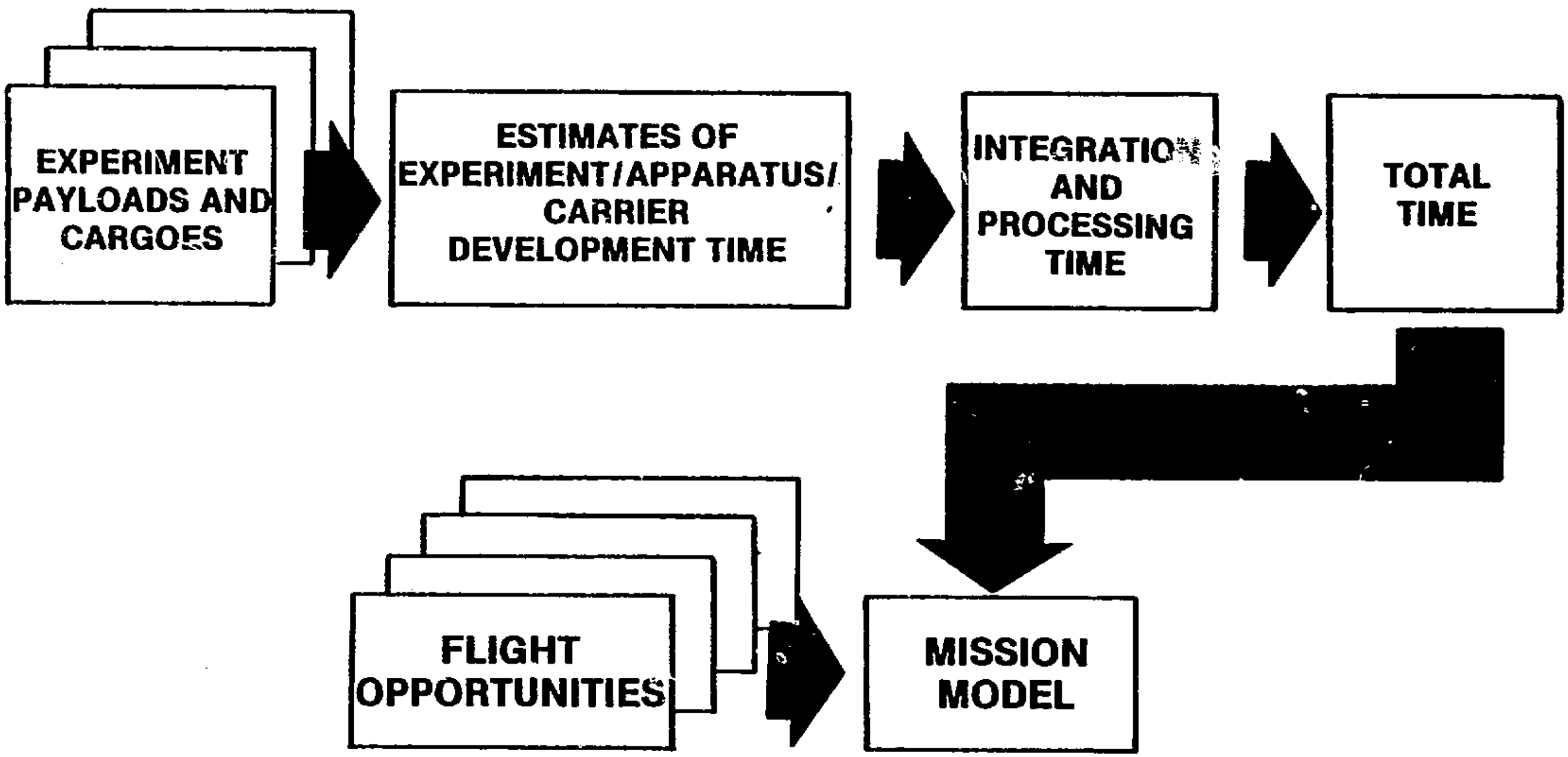
- User requirements for an experiment are matched to an apparatus (existing, modified, or new).
- The apparatus is matched to a carrier which accommodates the apparatus requirements.
- A flight (mission) which the experiment payload integration and processing time can achieve is tentatively identified.

In mission planning, time estimates are derived for the following:

- Estimates of experiment, apparatus, and carrier development time are made.
- Estimates of experiment integration and processing time are developed.
- Total time (sum of the above two above time estimates) is determined.

With the total time estimate, the STS mission model is examined to assure that the mission identified in the trades and analysis phase still remains achievable. If the total time estimate indicates that the initially-designated mission is not achievable or if for some reason the user is not satisfied, the analysis is routed back (via feedback loop) to the trades and analysis element and the process of deriving an alternative is initiated. The output of mission planning is a mission set for Commerce Lab.





MISSION PLANNING

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RESULTS

PROCESS DISCIPLINES

The currently identified elements of the microgravity science and applications program fall into three divisions:

1. **Material science**, including crystal growth, solidification of alloys and composites, and containerless processing.

2. **Physics and chemistry**, including fluid mechanics, transport phenomena, combustion science, cloud physics, and critical phenomena.

3. **Biotechnology**, including separation processes, suspension culturing, and blood rheology.

It was from these divisions that the six process disciplines were identified.

PROCESS DISCIPLINE

DISCIPLINE CODE	DISCIPLINE
BIO	BIOTECHNOLOGY
CS	COMBUSTION SCIENCES
EM	ELECTRONIC AND ELECTRO-OPTICAL MATERIALS
F&T	FLUIDS AND TRANSPORT PHENOMENA
G&C	GLASSES AND CERAMICS
M&A	METALS AND ALLOYS

AREA OF INVESTIGATION

The summary of areas of investigation identifies only those areas of significant potential for utilization by Commerce Lab. Since this area is dynamic, both the number of studies identified versus the availability of applicable data will continue to change through the duration of this activity.

AREA OF INVESTIGATION*

NUMERICAL BREAKDOWN OF STUDIES WITHIN EACH PROCESS DISCIPLINE

PROCESS DISCIPLINE	STUDIES WITHIN EACH DISCIPLINE/ STUDIES WITH COLLECTED DATA TO DATE
BIOTECHNOLOGY	13/12
COMBUSTION SCIENCES	3/3
ELECTRONIC MATERIALS	17/16
FLUIDS AND TRANSPORT PHENOMENA	25/24
GLASSES AND CERAMICS	13/12
METALS AND ALLOYS	14/14
TOTAL NUMBER OF AREAS OF INVESTIGATION	85/81

* CURRENT NASA MPS PROGRAMS AND PRIVATE COMMERCIAL STUDIES

INVESTIGATION CATEGORY

The following definitions must be understood to fully appreciate the divisions involved within the investigation category.

- **Scientific knowledge** identifies those activities intended to prove the validity of theories or concepts.
- **Process development** addresses the potential of improving or advancing current processing technology.
- **Product development** identifies those activities which would yield a useable commercial product.

Due to the complex nature of the studies, an activity may encompass one or more divisions within the investigation category. Thus, no numerical correlation exists between the area of investigation and its corresponding investigation category.

INVESTIGATION CATEGORY*

PROCESS DISCIPLINE	SCIENTIFIC KNOWLEDGE	PROCESS DEVELOPMENT	PRODUCT DEVELOPMENT
BIOTECHNOLOGY	9	8	3
COMBUSTION SCIENCES	3	1	0
ELECTRONIC MATERIALS	15	6	12
FLUIDS AND TRANSPORT PHENOMENA	22	6	5
GLASSES AND CERAMICS	11	8	4
METALS AND ALLOYS	14	2	6
TOTALS	74	31	30

* CURRENT NASA MPS PROGRAMS AND PRIVATE COMMERCIAL STUDIES

INVESTIGATION STATUS

The following definitions must be understood to appreciate the divisions/progress involved within the investigation status.

- **Analytical** identifies those studies which, at this time, exist in a purely conceptual development stage.
- **Ground-based** addresses those studies whose concept can be proven in a ground-based (Earth) laboratory.
- **Flight candidates** are those studies which by their nature can only be proven in a microgravity environment.

INVESTIGATION STATUS*

PROCESS DISCIPLINE	ANALYTICAL	GROUND BASED	FLIGHT CANDIDATE
BIOTECHNOLOGY	0	1	11
COMBUSTION SCIENCES	0	0	3
ELECTRONIC MATERIALS	1	1	14
FLUIDS AND TRANSPORT PHENOMENA	11	1	12
GLASSES AND CERAMICS	1	0	11
METALS AND ALLOYS	0	1	13
TOTALS	13	4	64

* CURRENT NASA MPS PROGRAMS AND PRIVATE COMMERCIAL STUDIES

FLIGHT CANDIDATES WITH COMMERCIAL APPLICATIONS

The significance of the chart on the facing page is contained in the column identified as known commercial interest. This column represents those companies with a stated interest in commercially utilizing the results obtained by a study.

FLIGHT CANDIDATES WITH COMMERCIAL APPLICATIONS*

PROCESS DISCIPLINE	POTENTIAL COMMERCIAL APPLICATIONS	KNOWN COMMERCIAL INTEREST
BIOTECHNOLOGY	11	7
COMBUSTION SCIENCES	1	0
ELECTRONIC MATERIALS	14	9
FLUIDS AND TRANSPORT PHENOMENA	4	3
GLASSES AND CERAMICS	9	4
METALS AND ALLOYS	4	3
TOTALS	43	26

* CURRENT NASA MPS PROGRAMS AND PRIVATE COMMERCIAL STUDIES

POTENTIAL FLIGHT CANDIDATES WITH KNOWN COMMERCIAL INTEREST

The following pages give a detailed list of the companies with a stated commercial interest in a particular study.

POTENTIAL FLIGHT CANDIDATES WITH KNOWN COMMERCIAL INTEREST

DISCIPLINE CODE	STUDY	INVESTIGATOR	COMMERCIAL INTEREST
BIO	Hormone purification by IEF in space	Dr. Milan Bier	Ionics, Inc.
BIO	Protein crystal growth	Dr. Charles Bugg	Upjohn Sherring-Plough
BIO	RIEF	Dr. Milan Bier	Sherring-Plough
BIO	CIEF	Dr. Milan Bier	Sherring-Plough
BIO	Electrophoresis in space	Dr. James Rose	MDAC Johnson & Johnson
BIO	Electrophoresis Pharmaceuticals	Dr. James Rose	MDAC Johnson & Johnson
BIO	Cell Growth Pharmaceuticals	Dr. Kenneth Ley	Lovelace Medical Foundation
EM	Characterization of Terrestrial and Spacelab Crystals of HgI_2	Dr. Wayne Schnepple	EG&G
EM	Solution growth of crystals in zero gravity	Dr. Ravendra Lal	Nite Vision Labs DOD
EM	Vapor growth of alloy-type semi-conductor crystals HgCdTe	Dr. Heribert Weidemeier	Honeywell, Boeing DOD, Hughes
EM	GaAs electroepitaxy		MRA
EM	Growth of GaAs crystals		Grumman Aerospace Alcoa GTE
EM	Organic crystal growth and thin film	Dr. Chris Posladly	3M

POTENTIAL FLIGHT CANDIDATES WITH KNOWN COMMERCIAL INTEREST

DISCIPLINE CODE	STUDY	INVESTIGATOR	COMMERCIAL INTEREST
EM	Organic crystal growth	Dr. Chris Posiadly	3M
EM	Solution crystal growth		Quantum Technologies
EM	Semiconductor materials PbSnTe	Dr. Roger Crouch	DOD
F&T	Production of large particle size monodisperse latexes (small 100 ml)	Dr. John Vanderhoff	NBS Particle Technology
F&T	Production of large particle size monodisperse latexes (large 2 l)	Dr. John Vanderhoff	NBS Particle Technology
F&T	Spaced-produced coatings	Dr. Richard Zito	SAI Wake Shield
G&C	Containerless processing of glass-forming melts in space	Dr. Delbert E. Day	DOD
G&C	Levitation studies of high temperature materials	Dr. John Margrave	G.E.
G&C	Foam stability	Dr. Gary Nishioka	Owens/Corning Fiberglass
G&C	Glass fiber pulling		DARPA Corning Glass
M&A	Orbiter processing of aligned magnetic composites	Dr. David A. Larson Dr. James Bethin	Grumman
M&A	Graphite formation in cast iron	Dr. Doru Stefanescu	John Deere Bethlehem Steele
M&A	Super Alloys	Dr. Pete Curreri	Pratt and Whitney

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POTENTIAL FLIGHT CANDIDATES WITHOUT KNOWN COMMERCIAL INTEREST

This page is a detailed list of the companies having an interest in a particular study but without a stated commercial interest in that study at this time.

POTENTIAL FLIGHT CANDIDATES WITHOUT KNOWN COMMERCIAL INTEREST

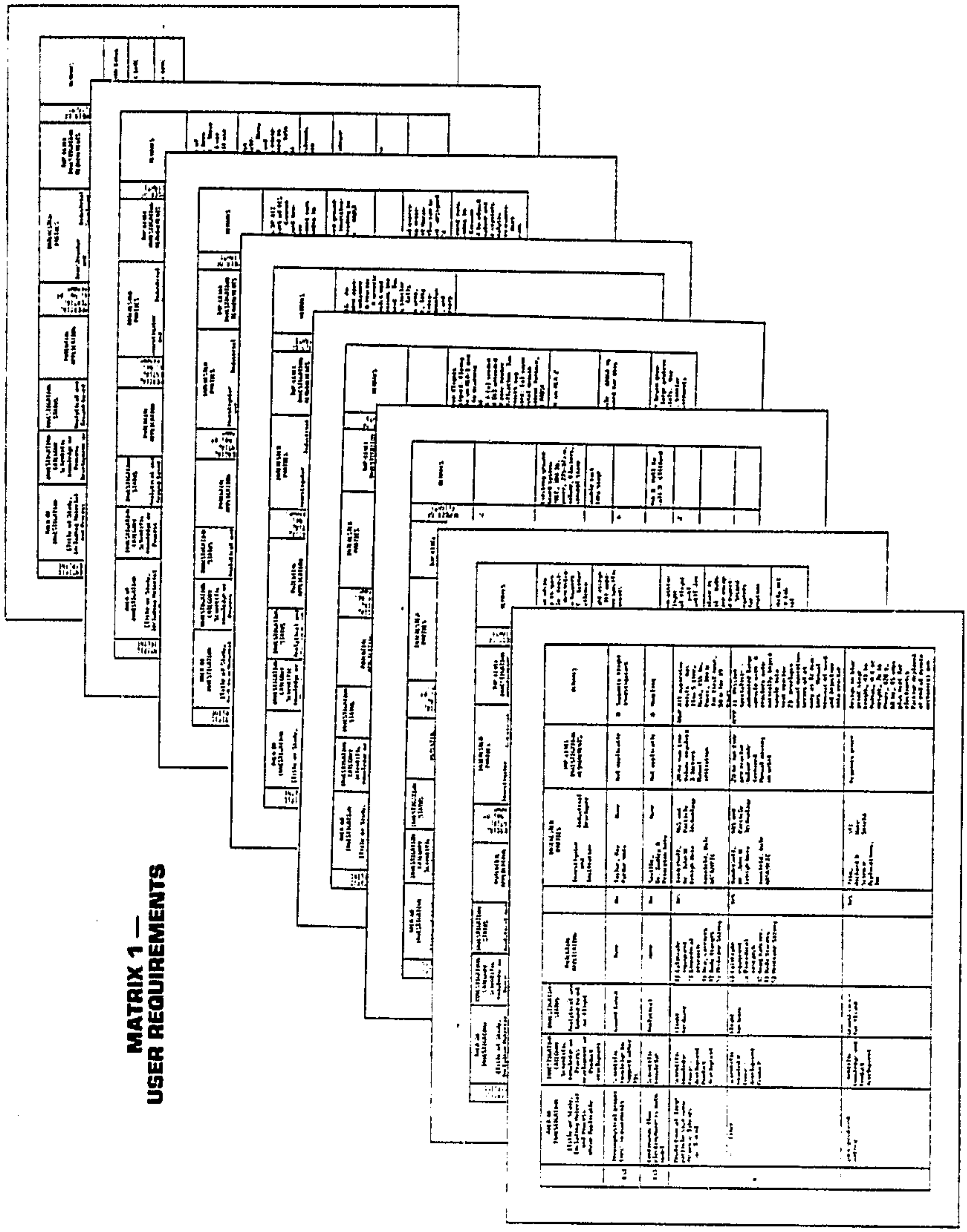
DISCIPLINE CODE	STUDY	INVESTIGATOR
BIO	Moving wall electrophoresis	Dr. Robert Snyder
BIO	New instrumentation for phase partitioning	Dr. J. Milton Harris
BIO	Aggregation of red blood cells	Dr. Leopold Dintenfass
BIO	Cell partition in two-layer aqueous phases	Dr. J. Milton Harris Dr. Donald Brooks
CS	Droplet Combustion	Dr. William Forman
EM	Growth of GaAs crystals from the melt in a partially confined configuration	Dr. Harry C. Gatos Dr. Jacek Lagowski
EM	Microgravity silicon zoning investigation	Mr. Edward Kern
EM	Semiconductor materials' growth in low-gravity environment PbSnTe	Dr. Roger K. Crouch Dr. Archie Fripp
EM	Protein crystal growth in low gravity	Dr. R. S. Feigelson
EM	Growth of solid solution single crystals HgCdTe	Dr. S. L. Lehoczky
F&T	Test of new thermodynamic model of impurity extraction by droplets	Dr. G. Morrison Dr. J. Kinkaid
G&C	Microstructural analysis of Nb-Ge drop tube specimens	Dr. Robert Bayuzick
G&C	Influences of containerless undercooling	Mr. E. W. Collings
G&C	The upgrading of glass microballoons	Dr. Stanley Dunn
G&C	Homogenous crystallization studies of borderline glass forming systems	Dr. Ed Ethridge
G&C	Ultrapure glass optical wave guide development in Microgravity by the sol-gel process	Dr. Shyama Mokherjee
M&A	Directional solidification of liquid miscibility gap material	Dr. M. H. Johnston

MATRIX I - USER REQUIREMENTS

The attached matrix was formulated utilizing all salient information necessary for the identification of potential Commerce Lab candidates. The categories identified by this matrix are either self-explanatory or addressed in sufficient detail later in this package. It is noted that only science requirements are included herein and not physical resources--such as power and heat rejection--required by apparatus. Typical science requirements include run time, operating temperature, number of samples to be processed, number of flights, etc. See Matrix II for apparatus physical requirements.

MATRIX I - USER REQUIREMENTS

- SCIENTIFIC DISCIPLINE
- AREA OF INVESTIGATION
- INVESTIGATION CATEGORY
- INVESTIGATION STATUS
- POTENTIAL APPLICATION
- COMMERCIAL POTENTIAL
- INTERESTED PARTIES
- TOP-LEVEL PROCESS REQUIREMENTS
- NUMBER OF FLIGHTS
- REMARKS (POTENTIAL APPARATUS)



MATRIX 1 —
USER REQUIREMENTS

MATRIX II – APPARATUS

The Apparatus Matrix, shown on the following page, is self explanatory with the acception of the divisions involved in the apparatus status and characteristics. The apparatus status identifies the current development stage of both ground and flight units as being

Existing	E
Under development	U
Planned	P
Needed	N

Apparatus characteristics:

The functional column identifies the major components of the apparatus.
The operational column identifies the detailed operating capacities of the system.
The resource requirements addresses the electrical/mechanical services to be supplied by the Orbiter.
The physical parameters column is self explanatory (i.e. dimensions, mass, etc.).

MATRIX II - APPARATUS REQUIREMENTS

- NAME
- STATUS
- DEVELOPER
- APPLICATIONS
- CHARACTERISTICS
  - FUNCTIONAL
  - OPERATIONAL
  - CARRIER RESOURCE REQUIREMENTS
  - PHYSICAL PARAMETERS
- AVAILABILITY

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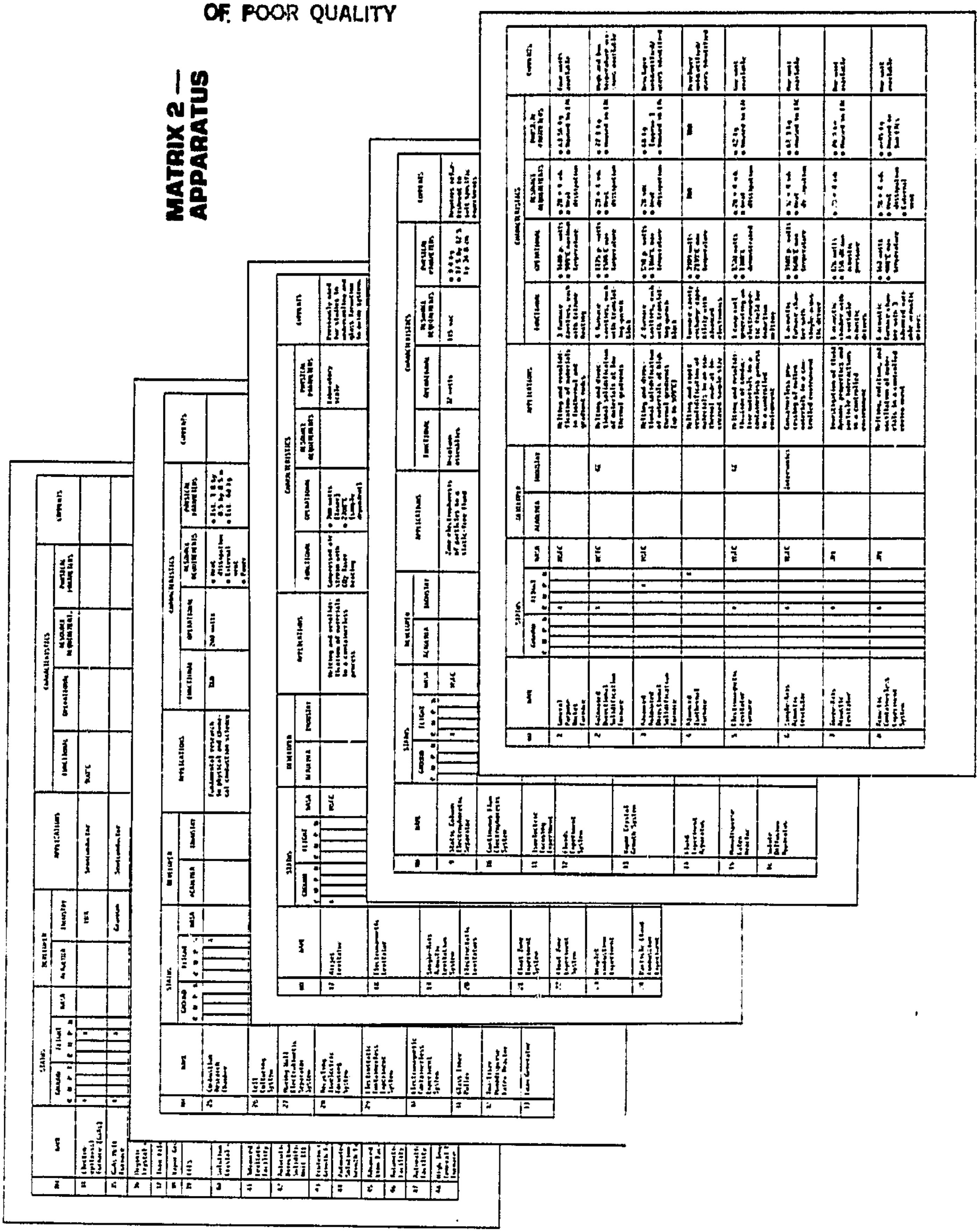
MATRIX 2 — APPARATUS



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MATRIX III – CARRIER CAPABILITIES

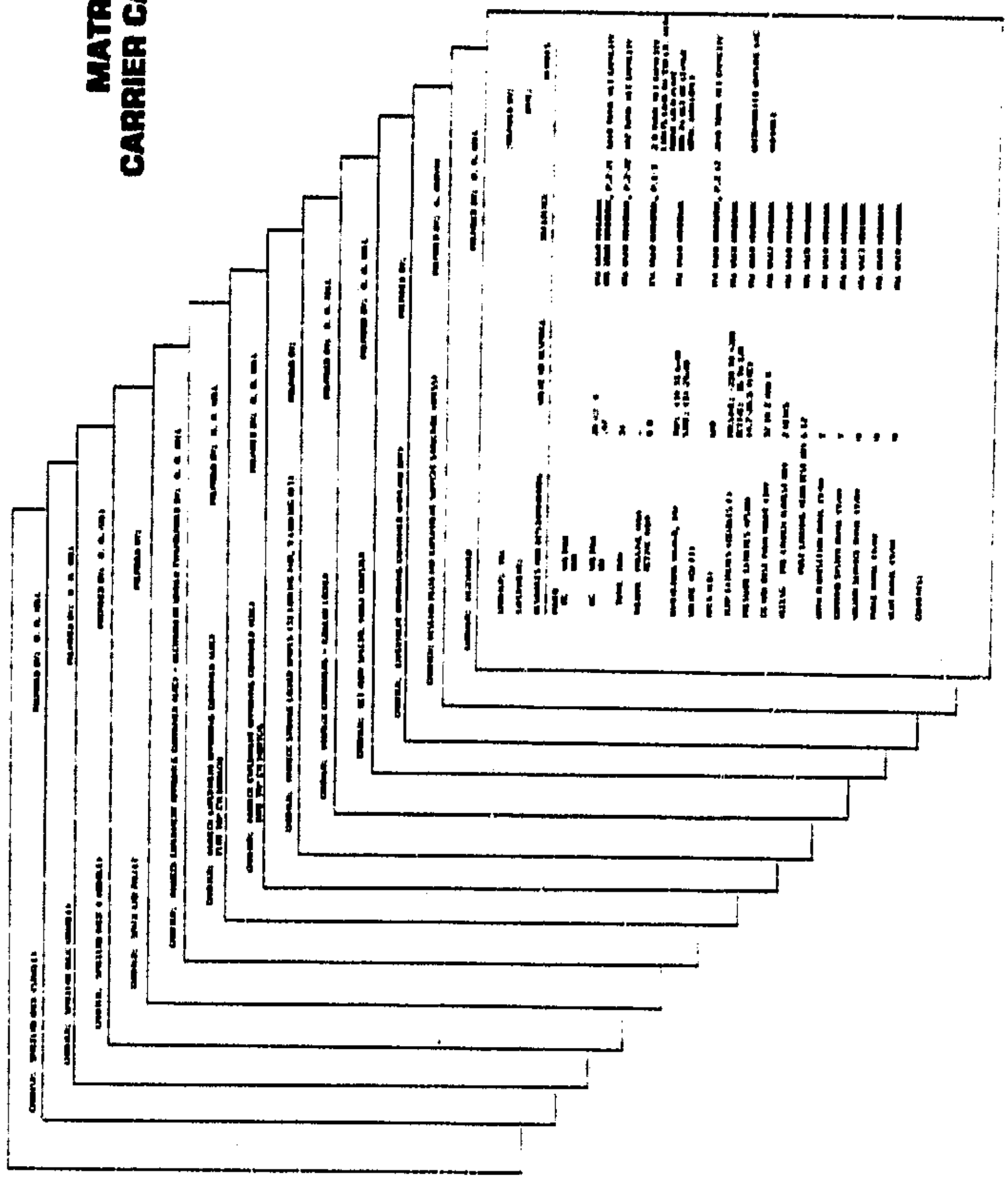
The Carrier Capabilities Matrix identifies resources and discriminators which are generally important in initially matching apparatus and other user requirements with carrier capabilities. Some data shown in this matrix are not absolute values. Also, some carrier guidelines permit the stated capabilities to be exceeded. Where a requirement only marginally exceeds a capability or where a capability other than those shown in needed, the mission planner refers to the extensive backup data base that has been assembled in this project.

This information will be updated during the program where other carriers are identified for use on Commerce Lab, where carrier capabilities are changed, or where it is determined that additional resources or discriminators should be provided by the matrix. Also provided are the references for the source data, remarks to expand on or provide clarification to source discriminator information, and comments of a general nature applicable to a specific carrier.

MATRIX III - CARRIER CAPABILITIES

- ELECTRICAL POWER
- HEAT REJECTION CAPABILITY
- MAXIMUM PAYLOAD DIMENSIONS
- MAXIMUM PAYLOAD VOLUME
- MAXIMUM PAYLOAD MASS
- AMBIENT TEMPERATURE EXTREMES
- AMBIENT PRESSURE EXTREMES
- CDMS CAPABILITY
- VACUUM, PURGE, VENT CAPABILITY
- PRE-LAUNCH/POST-LANDING ACCESS
- INTEGRATION TIME FRAME

MATRIX 3 —
CARRIER CAPABILITIES



INTEGRATION STUDY

- CARRIER INTEGRATION TIMES
- APPROACH TO MINIMIZING USER INTERACTION
  - PROCESS
  - HARDWARE

INTEGRATION EFFORT VERSUS INTERFACE REQUIREMENTS

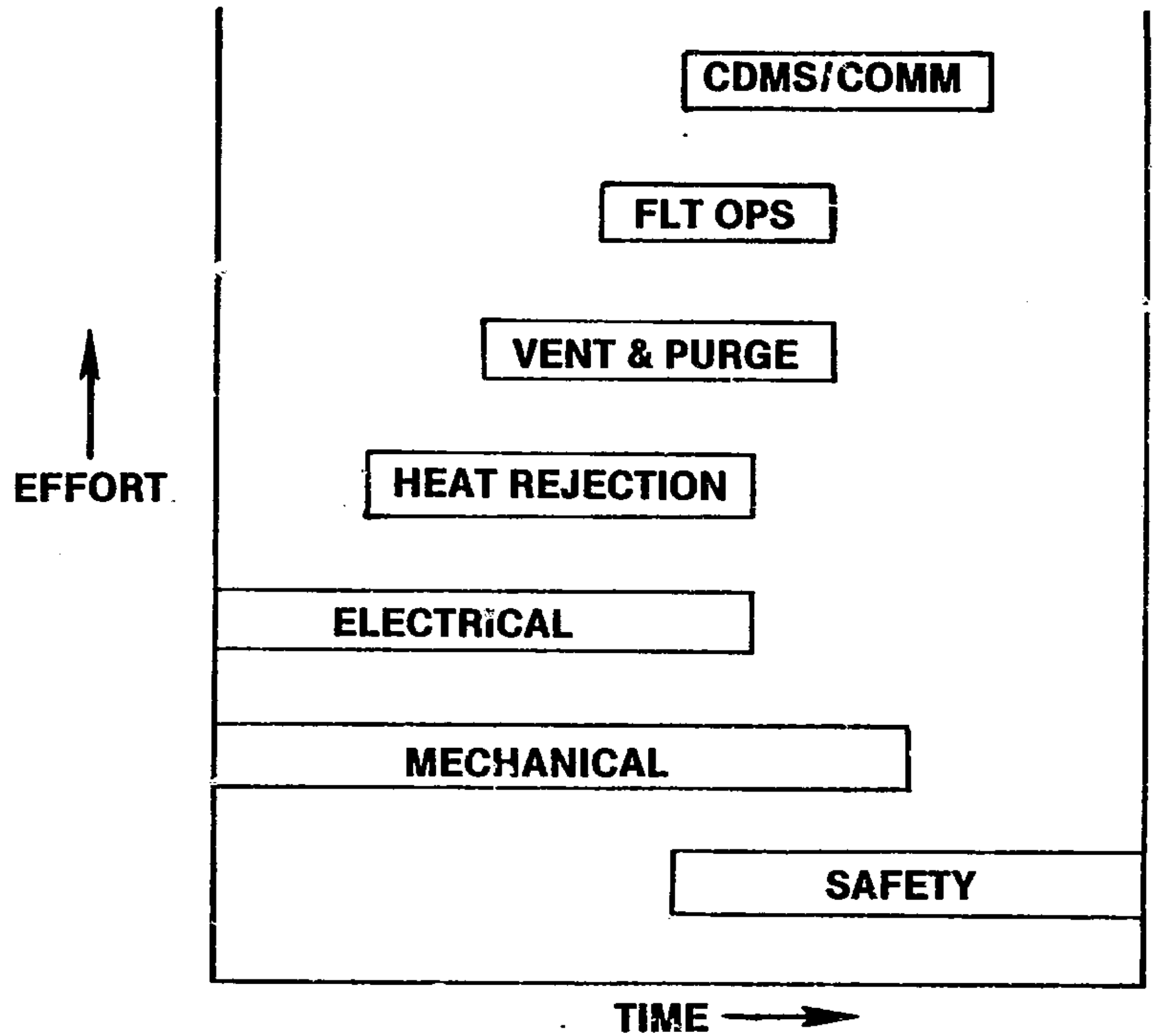
As a part of the initial study of payload integration, an attempt was made to express integration time as a function of interface requirements; that is, number and complexity of interfaces requiring integration. It was determined that although each interface discipline (mechanical, electrical, CDMS, etc.) required a certain amount of effort on the part of the experiment developer and payload integrator, integration time prior to Level IV was largely determined by the single most complex and time consuming interface and independent of the total number of interfaces. This controlling interface is usually mechanical, electrical, or a combination of both, which is common to all carriers. In other words, reducing the number and/or complexity of interfaces required to be integrated will reduce the integration effort but have little or no effect on time required to accomplish payload integration.

The second chart, percent of total effort by interface, attempts to show the relative complexity of the interface integration required within a specific carrier, expressed in terms of integration effort. For example, Spacelab Module indicates that 20 percent of the total integration effort prior to Level IV is devoted to mechanical interfaces. This percentage assumes that all interfaces require integration; a higher percentage of the total would be devoted to mechanical interfaces if the number of interfaces requiring integration were reduced. Also these percentages are generic estimates and will vary according to complexity and requirements of total mission payload.

However, GAS Can indicates that 30 percent of the integration effort is devoted to mechanical interfaces. This should not be taken to mean that a GAS Can is mechanically harder to integrate or requires more time; instead, it indicates that more of the effort required to integrate a GAS Can is devoted to the mechanical interfaces.

The times given under "Integration Onto Carrier (Pre-Level IV)" are estimates based on prior experience and/or mission manager estimates. The second column, "Integration Onto STS", is KSC integration and is often influenced by total mission payload integration requirements. The columns are additive for each payload to give relative total integration time between types of carriers.

TYPICAL INTEGRATION ONTO CARRIER BY INTERFACE



PERCENT OF TOTAL INTEGRATION EFFORT (MANPOWER) AS A FUNCTION OF INTERFACE REQUIREMENTS

CARRIERS ↓ / INTERFACES →	MECHANICAL	ELECTRICAL	SAFETY	FLT OPERATIONS (TRNG/FLT PLAN)	OPERATIONS SUPPORT	CDMS (COMMAND/DATA ACQUISITION & STORAGE)	COMMUNICATIONS (VOICE/VIDEO/DATA)	HEAT REJECTION	VENT AND PURGE	PRE-LAUNCH ACCESS	POST-LANDING ACCESS	INTEGRATION TIME (MONTHS): INTEG. ONTO CARRIER (PRE LEV IV)	INTEGRATION TIME (MONTHS): INTEG. ONTO STS (LEV IV TO LAUNCH)
SPACELAB MODULE	20	20	10	10	10	7	7	5	5	3	3	24 TO 36	8 TO 12
SPACELAB RACK	20	20	10	10	10	7	7	5	5	3	3	18 TO 24	8 TO 12
SPACELAB PALLET	25	25	10	10	7	7	5	5	2	2	2	12 TO 18	6 TO 10
MSL	25	25	10	10	10	8	—	5	3	2	2	12 TO 15	6 TO 8
GAS CAN	30	30	10	8	5	5	—	5	3	2	2	8 TO 12	4 TO 6
MIDDECK LOCKER	30	30	10	8	5	5	—	5	3	2	2	8 TO 12	4 TO 6
MPESS	40	35	10	5	5	—	—	—	—	3	2	8 TO 12	6 TO 8
HITCHHIKER	25	25	10	7	7	7	5	5	3	3	3	6 TO 9	4 TO 6

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COMMERCE LAB

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WYLE LABORATORIES

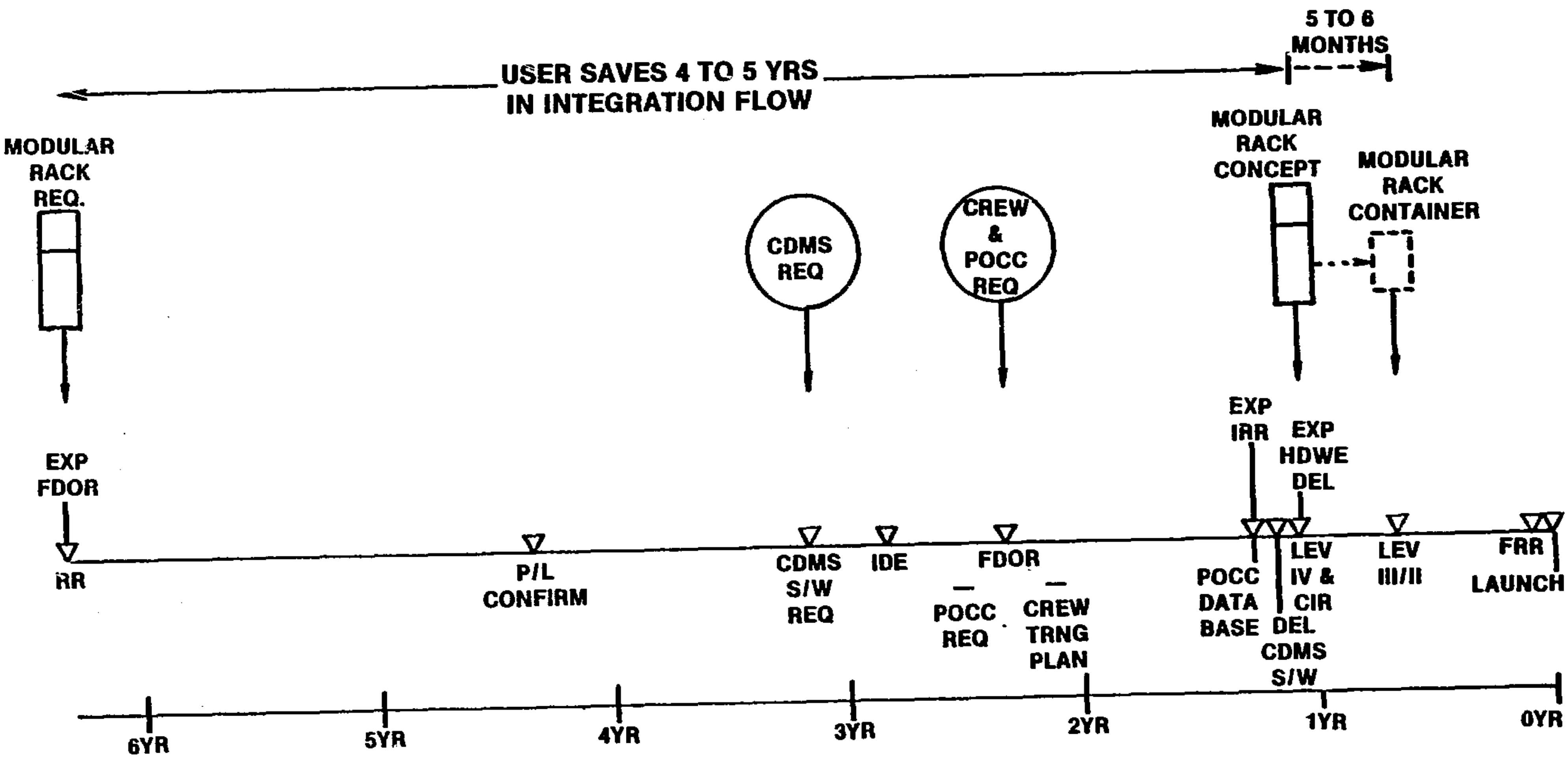
MINIMAL USER INTERACTION APPROACH

The Minimal User Interaction Approach is seen as a possible solution to the problems encountered by a user during the payload integration cycle. Using the integration of Spacelab as a worst-case example, a typical user would be required to input design data as early as six years prior to launch and have deliverable flight hardware available as early as one year prior to launch. The user is thus forced to extend his development over a money and time-consuming schedule.

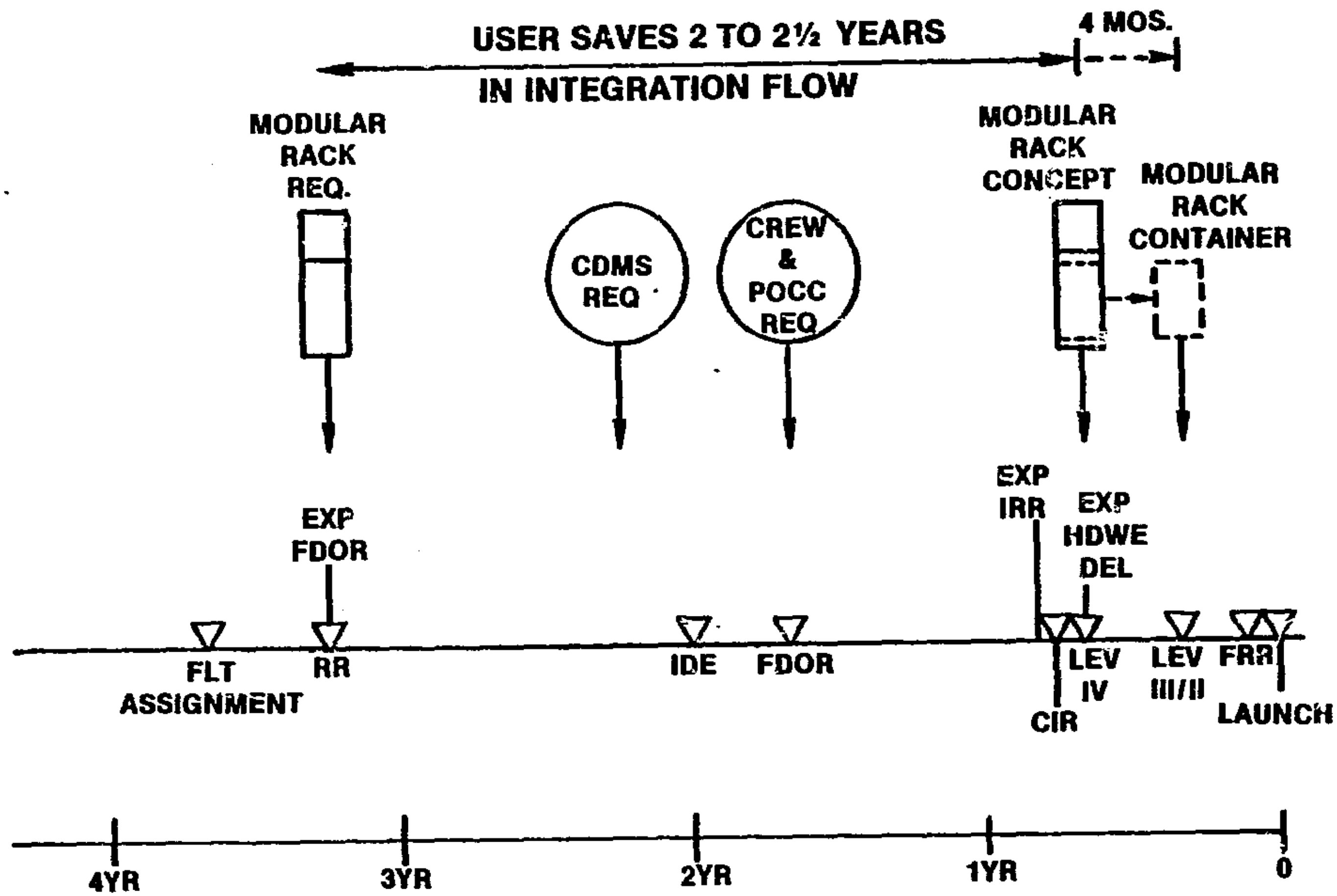
Minimal user interaction would allow the user to adjust his development schedule to fit his own needs and restraints without adversely affecting the normal STS integration flow. A "standardized" set of resources on a particular flight is reserved and integrated into the total payload using predetermined maximum values. A user restricted to these maximum values is then allowed to enter the integration cycle at a much later date, thereby conserving resources and making the utilization of STS much more attractive to commercial users.

Using the most optimistic integration timeline developed by SMICA, the Minimal User Interaction Approach would enable a user to save approximately two years. The Modular Rack concept would provide additional savings by utilizing standardized interfaces to accept a plug-in module within a Spacelab rack.

MINIMAL USER INTERACTION APPROACH USING SPACELAB MISSION 3 SCHEDULE



MINIMAL USER INTERACTION APPROACH USING SMICA NEW MISSION SCENARIO



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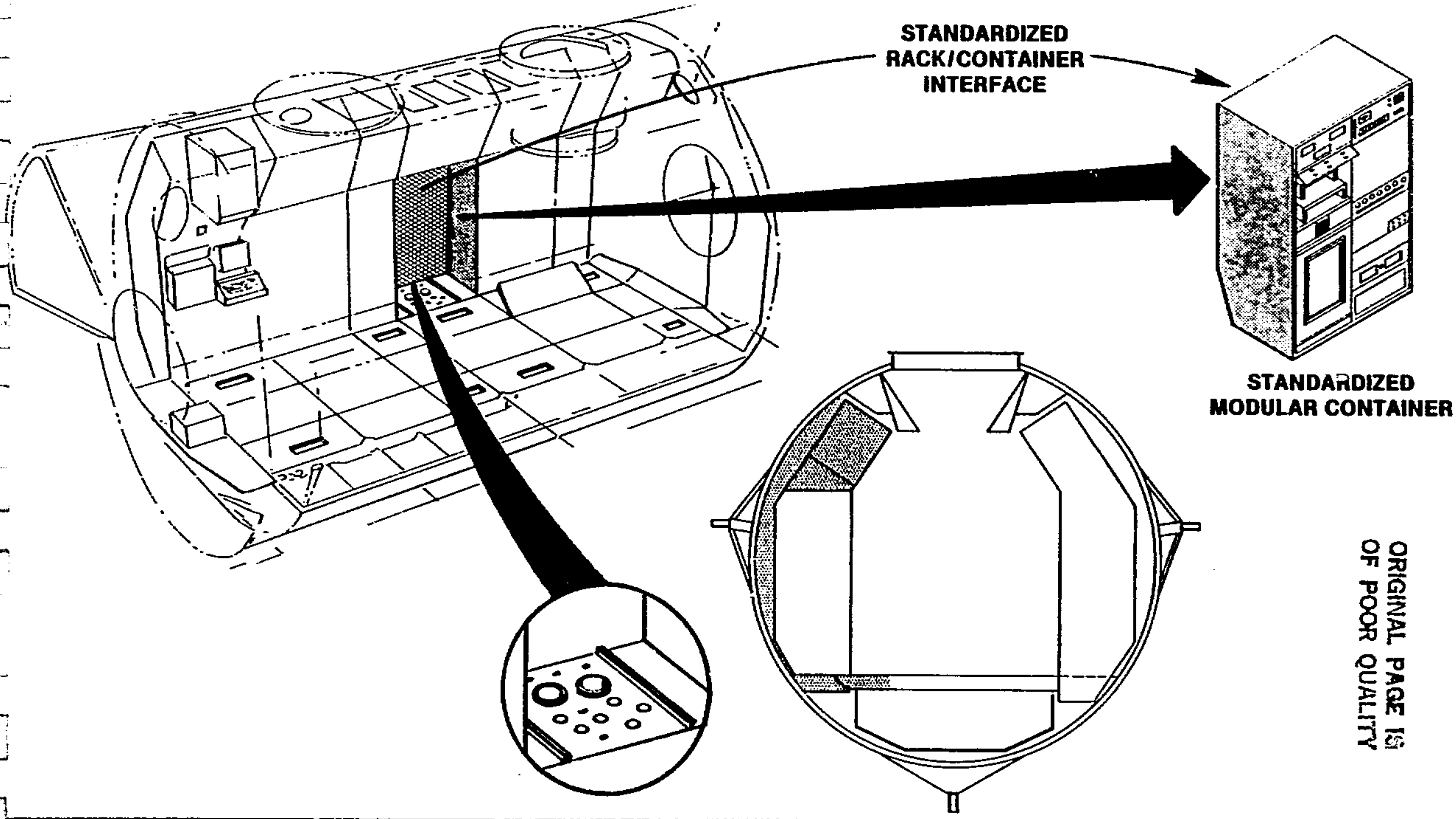
MODULAR RACK CONCEPT

The Modular Rack concept would provide a standardized rack/container interface within the Spacelab Module. A standardized container would be utilized for the accommodation of customer payloads with standard functional interfaces provided for suitable utility connections. Standard utility connections would be incorporated to accommodate container integration with minimum installation, activation, and system checkout. This approach would minimize the constraints imposed on the customer while maximizing commonality through the use of common interfaces, standardized geometries, standardized resource supply connectors and interfaces, and all other factors that facilitate and provide flexibility for payload integration. An additional feature of the modular concept would be a standardized design for the utilization of available space within the upper section of the proposed double rack design.

MODULAR RACK CONCEPT



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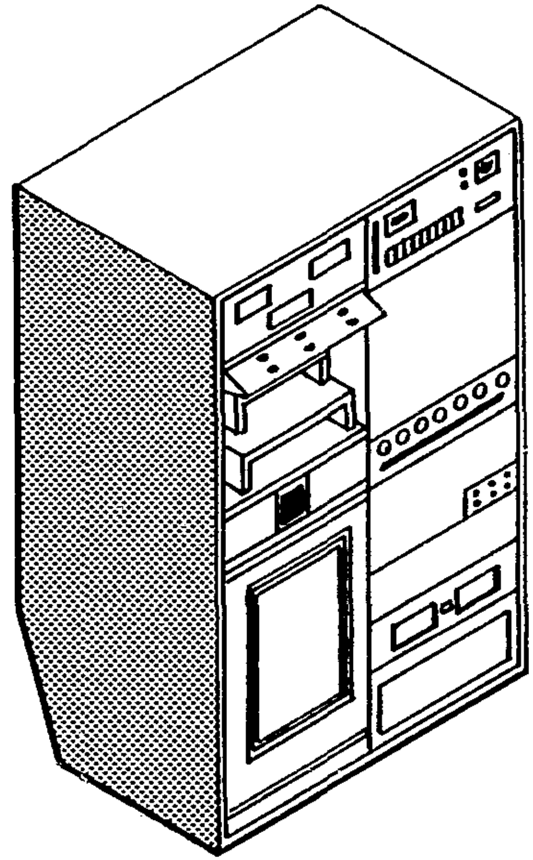
TYPICAL MODULAR CONTAINER OUTFITTING

The typical outfitting of a Modular Container would include standardized functional interfaces for mechanical, electrical, and thermal utilities provided by the Spacelab module. Customer payload requirements would define the experiment and/or processing apparatus and supporting subsystems required for inclusion in the standardized Modular Container. A standardized control and monitor system would be incorporated into the container that would provide a microprocessor for the control, monitoring, and data acquisition of the experiment and/or processing variables. Process control could be optional, depending on the real-time assessment required by a payload specialist or the payload's apparatus automation capability.

TYPICAL
MODULAR CONTAINER OUTFITTING

- STANDARDIZED CONTROL AND MONITOR SYSTEM
  - MICROPROCESSOR
  - CONTROL PANEL (CRT)
  - DATA ACQUISITION
- STANDARDIZED INTERFACES
  - MECHANICAL
  - ELECTRICAL
  - THERMAL
- EXPERIMENT/PROCESS APPARATUS AND EQUIPMENT



APPROACH TO MINIMIZING USER INTERACTION

- MAXIMUM REQUIREMENTS DEFINED AND RESERVED AT REQUIREMENTS REVIEW
- WILL ALLOW USER WITH LIMITED REQUIREMENTS TO ENTER INTEGRATION FLOW AT LAUNCH MINUS 6 TO 9 MONTHS, THEREBY SAVING 2 TO 3 YEARS IN FLOW
- USER LIMITED TO PRE-DEFINED ALLOCATABLE RESOURCES (MASS, CG, DIMENSION, POWER DRAW, HEAT REJECTION, ETC.)
- USER REQUIRED TO INPUT REQUIREMENTS ON NON-ALLOCATABLE RESOURCES 12 TO 18 MONTHS PRIOR TO HARDWARE DELIVERY (CDMS, POCC, CREW, ETC.)

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SUMMARY

PROGRESS TO DATE

Substantial progress has been made to date on the Commerce Lab study to develop a commercial mission model for NASA in the microgravity sciences. The first task in the study was to assemble the user requirements' data base. The data format was designed specifically for this study since numerous considerations are involved in the diverse disciplines. The user data were obtained through the literature, telephone calls, and interviews with MSFC personnel. Matrix I, User Requirements, contains user information such as run time, number of samples, operating temperature, etc. Matrix I specifies existing apparatus to be used as appropriate. Matrix II, Apparatus, contains parameters relating directly to apparatus such as power, heat rejection, size, etc. Matrix III, Carrier Capabilities, defines the capabilities of existing carriers. These three matrices, which are 90 percent complete, contain the necessary information for the mission planning task.

Also, considerable time has been spent developing a logical approach for the mission tasks. These mission tasks will be addressed in the remainder of the contract.

At the request of NASA, a quick look was made into the integration process since it is well known that potential commercial users view the long integration times associated with space flight as a barrier to space commercialization. A potential approach to minimize impact on user integration time is discussed in this report.

PROGRESS TO DATE

- DEVELOPED REQUIREMENTS MATRIX
- OBTAINED DATA ON USERS' PROCESSES
- DEFINED OVERALL APPROACH
- DEVELOPED APPARATUS MATRIX
- DEVELOPED CARRIER MATRIX
- INITIATED ACTIVITY ON NEW INTEGRATION CONCEPTS
- INITIATED ACTIVITY ON INFRASTRUCTURE

OBSERVATIONS AND CONCLUSIONS

Several observations and conclusions have surfaced. First, the commercialization of space is becoming a reality in the area of microgravity sciences. Commerce Lab can focus this commercialization, and, in fact, the existence of a Commerce Lab program could be expected to entice new commercial investigations. The NASA commercial working group has stated that the United States should provide a pressurized flight once a year to accommodate commercial users. Commerce Lab can fulfill this need, and Commerce Lab can be used as a stepping-stone to Space Station commercial activities. Also, Commerce Lab can be used to advance microgravity sciences. Hence, Commerce Lab can become the flagship for space commercialization over the next decade.

Next, the amount of commercial space traffic in microgravity sciences is substantial and is growing with time. In addition, it should be recognized that most commercial investigations require multiple flights (which substantially increase the traffic). The traffic is such that both missions of opportunity and periodic dedicated missions are anticipated to be required. (This conclusion will be analyzed more closely during the remainder of the study.)

Apparatus availability is an important consideration for several reasons. The diversity between the six microgravity disciplines means that the various apparatus cover a wide spectrum. Many of the investigation's requirements are quite severe. For instance, low temperature gradients are required at about $1000^{o}C$. Apparatus must be able to interface with the carriers and must operate within the physical resources available. The control of fluids in microgravity is often a consideration. Since it can take two years and considerable manpower to develop apparatus, the inventory of current appratus, though substantial, is not sufficient to meet current needs. For example, John Deere requires that over 100 samples be run. Since no existing furnace has an automatic sample exchanger, this requirement cannot be met with a few flights since only four specimens can be simultaneously processed in the existing furnace. It is also noted that if a large variety of apparatus existed, then more commercial customers could be anticipated. Hence, apparatus availability is a limiting factor.

It is noted that it is the apparatus which consumes the resources such as power and heat rejection. The consumption of electrical power in a furnace depends on the operation temperature, temperature gradient, sample size, and number of specimens. (This accounts for some of the differences in quoted power consumption rates.)

Commercial users regard time as money; hence, lengthy integration times are viewed by commercial users as an economic barrier to accomplishing space commercialization. Therefore, faster integration by the user is essential. Commerce Lab can play a role in Space Station by becoming a test facility for Space Station development.

OBSERVATIONS AND CONCLUSIONS

- COMMERCE LAB CAN BE THE FLAGSHIP FOR SPACE COMMERCIALIZATION OVER THE NEXT DECADE
- COMMERCIAL MPS USER TRAFFIC IS ANTICIPATED TO BE SUBSTANTIAL
  - USER REQUIREMENTS ARE ANTICIPATED TO EVOLVE RAPIDLY OVER THE NEXT YEAR OR TWO
  - MANY INVESTIGATIONS WILL REQUIRE MULTIPLE FLIGHTS
- BOTH MISSIONS OF OPPORTUNITY AND PERIODIC DEDICATED MISSIONS APPEAR TO BE NEEDED & SUPPORTED BY EARLY ADVANCED PLANNING
- APPARATUS AVAILABILITY IS ANTICIPATED TO BE A KEY LIMITING FACTOR
- NORMALLY, SAMPLE TEMPERATURE, GRADIENT, SIZE, NUMBER, AND PROCESS TIME DRIVE THE RESOURCE REQUIREMENTS
- OPTIMUM CUSTOMER ACCOMMODATION OF COMMERCIAL USERS WILL REQUIRE NEW INTEGRATION CONCEPTS
- COMMERCE LAB CAN BE USED TO DEVELOP APPROACHES TO SPACE STATION CUSTOMER ACCOMMODATIONS
  - STANDARDIZED INTERFACES
  - SIMPLE ON-ORBIT PAYLOAD INTEGRATION
  - PAYLOAD PACKAGING CONCEPTS

FUTURE WORK

On-going Effort (in the contract)

During the remainder of this study, the major emphasis will be placed upon mission trades and analysis, mission planning, and development of a mission model. Of course, Wyle will continually update the data matrices as required.

Suggested New Work (not currently in the contract)

The time is appropriate to plan a Commerce Lab symposium that would be designed to attract potential commercial users of Commerce Lab. Also, additional work is needed on rapid user integration. Using Wyle's minimal user impact integration concept to develop an experiment rack mockup for use in the symposium is also suggested.

FUTURE WORK

- ON-GOING EFFORT
  - CONTINUE DEFINITION OF USER REQUIREMENTS
  - PERFORM EXPERIMENT TRADES AND ANALYSIS
  - PERFORM MISSION PLANNING
  - DEVELOPMENT OF MISSION MODEL WITH CAPABILITY FOR ON-GOING UPDATING
- SUGGESTED NEW WORK
  - CONSTRUCT A MODULAR RACK MOCK-UP
  - DEVELOP MINIMAL USER INTERACTION CONCEPTS TO INTEGRATION